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Resources, Environment, and Population: The Nature of Future Limits

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Resources, Environment, and Population: The Nature of Future Limits

By Ronald G. Ridker and Elizabeth W. Cecelski

Abstract—This *Bulletin* examines the balance between world supplies of resources and the demands presented by population and economic growth in the recent past, during the period to 2025, and for the long term. Improvement in socioeconomic indicators, relatively stable resource market prices, and evidence of resource and environmental changes suggest that so far the world as a whole has been winning the race between demand and supply. For the next half century, during which a slowdown is projected in growth rates of both population and resource consumption, the most important problems to be faced are associated less with physical exhaustion of resources than with their unequal distribution and the transition problems of moving from one resource regime to another in an orderly fashion. For the long term, a projected equilibrium population of 10 to 12 billion can probably be sustained at a decent standard of living by more equitable distribution of food and shifts from less to more abundant resources: in nonfuel minerals, from such resources as tin, tungsten, and lead to aluminum, cement, and glass; and in energy, from oil and natural gas to coal, various forms of solar energy, and possibly nuclear fusion. Ultimately, environmental and security problems associated with growing energy production and use such as increasing atmospheric levels of carbon dioxide and nuclear proliferation may be the most difficult to resolve. Cessation of population growth would help but by itself does not constitute a solution to the world's resource problems.

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Contents

	Page
Introduction	3
The issues	5
The Past: Winning or Losing?	7
Socioeconomic indicators show improvement	7
Past trends in market prices	10
Specific evidence of depletion	12
The answer?	18
Future Demands	18
Population projections	18
Growth in per capita demand	20
Resource Supplies to 2025	24
Current and prospective reserves	25
Aluminum	27
Nickel, copper, cobalt	27
Oil	27
Economic impact of rising prices	28
Overall picture to 2025	29
Ultimate Resource Production Possibilities	31
Food production	31
Nonfuel minerals	32
Energy	32
Environmental Constraints and Risks	34
Problems capable of control at reasonable cost	34
Other domestic environmental problems	35
Potentially severe global problems	36
Implications	37
References	40
Selected Bibliography	42

Figures

1.	Price Trends for Selected Major Resources: U.S., 1870 to 1977	11
2.	World Production Per Capita of Some Renewable Resources: 1960 to 1978	14
3.	World Oil Production Per Capita: 1950 to 1978	16
4.	International Oil Prices, Current and Deflated Dollars Per Barrel: January 1970 to July 1979	17
5.	World Energy Consumption: 1975, 2000, 2025, and 2050	23
6.	The Resource Base	26

Tables

1.	Selected Socioeconomic Indicators: 1960 to 1976	8
2.	Annual Rate of Increase in Food Production in Relation to Population: Developed and Developing Regions, 1961 to 1975	9
3.	Average Annual Rates of Population Growth, 1950 to 1980, and Selected Projections to 2000	19
4.	World Consumption and Rates of Growth in Consumption of Selected Resources: 1971 to 2050	22
5.	Estimated and Projected World Energy Consumption and Population: Developed and Developing Regions, 1972, 2000, and 2025	24
6.	Dates When Price Must Rise to Avoid Exhaustion of Selected Resources	26

Wide World Photos

Gasoline problems in 1979 stemmed more from a production slowdown during Iran's revolution and steep price rises set by the OPEC cartel than from a shortage of world oil resources. However, global resources of petroleum and natural gas are projected to be exhausted in the next 50 to 75 years and the world must prepare to deal with the transition problems of shifting to alternative sources of energy.

Resources, Environment, and Population: The Nature of Future Limits

By **Ronald G. Ridker**
and **Elizabeth W. Cecelski**

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The authors are grateful for the help provided by Jean van der Tak in preparing this Bulletin.

Speculation about the future of man has been a scholarly pastime for centuries. But in recent years, especially in richer industrialized societies, idle speculation has given way to urgent debate on current policies as the conviction grows that the shape of the future can and must be controlled if problems are to be avoided.

Two views prevail. The first, which can be called the *Limits Thesis*, involves four propositions:

First, it is asserted, there are definite limits to population and economic growth, limits which are imposed by the finiteness of the earth—by the fact that air, water, minerals, space, and all usable energy sources consist of fixed stocks that can be exhausted or flows that can be overloaded.

Second, these limits are very near.

Third, if we permit ourselves to approach these limits too closely, worldwide death rates will soar.

Fourth, even if these limits are further away than we think, population and economic growth *ought* to stop: after a certain point, already exceeded by the rich in both developed and developing countries, the quality of life may actually decline with the introduction of more and more material goods; present wasteful consumption habits are using up resources that ought to be conserved for future generations; and, if the rich would consume less, more would be left for the poor of the world.

As evidence that these limits are near, advocates of this view point to current energy and food problems, to areas of the earth now beset by deforestation, erosion, and desertification, and to the fact that current reserves of many minerals will not last for long if the

growth in their consumption continues at present rates.

The opposing view is sometimes called the *Cornucopian Thesis*. It asserts:

First, there are limits to growth only if science and technology cease to advance, but there is no reason why such advances should cease. So long as technological development continues, the earth is not really finite, for technology *creates* resources.

Second, even if scientific advances were to cease, the limits would still be far away: the earth is yet huge relative to the demands being made upon it by man, and the possibilities for substituting more abundant for scarcer resources are so great that there is no reason why population and economic growth cannot continue for a very long time.

In any event, according to this view, growth is good: no society has reached the point where all its material needs are satisfied; growth is the only practical way to create a surplus that can be redistributed to the poor; and growth poses challenges for humanity, giving life a sense of purpose and encouraging greater achievements.

The "Cornucopians" believe that past history provides their best evidence. If one sees behind him a relatively steady stream of progress in material welfare and no signs that technological developments are slowing down, he may reasonably ask why all the concern about the future.

Clearly, the Limits Thesis is on the ascendancy today. But it is worth remembering that neither of these views is new. The Cornucopian view is rooted in the biblical injunction to be fruitful and multiply. The Limits Thesis goes back at least to Malthus who argued in the late 18th century that population, if unchecked, would grow geometrically (2, 4, 8, 16, etc.) while food production could only grow arithmetically (2, 3, 4, 5, etc.). Thus, the standard of living would always tend toward the minimum subsistence level. Malthus wrote his *Essay on Population* in response to his father's optimistic views on the possibility of material progress and a future egalitarian society.[1]

Such cycles of pessimism and optimism have occurred throughout history, and this is unlikely to change. For the future is essentially unknowable. So long as this is the case, views of the future will be dominated by today's problems, perceptions, and moods, which are not necessarily long lasting. Considering the spate of immediate problems this globe now faces, it is little wonder that the pessimists are currently on the ascendancy.

The critical question today is whether this pessimism is more than just another cycle. To what extent is this most recent change of heart about the future of humanity associated with new information about resource and environmental constraints? Has something in the physical or economic world changed to make serious shortages of material or environmental resources more imminent today than they seemed to be just 10 or 20 years ago? Most importantly for this *Bulletin*, what role does population growth play in these potential constraints?

Our own view is that the debate between these two schools is falsely polarized and has become unproductive. The relevant question is not whether to grow or not to grow, but how to redirect present and future economic output in ways that will better serve humanity. Clearly there are physical constraints to population and economic growth, but most of them are distant enough to be managed by adequate planning, good will, and international cooperation—provided we do not procrastinate. For the present our most serious problems are the political, social, and institutional barriers to getting on with the job. A slowdown in the rate of growth—particularly population growth—is important because it reduces the number and intensity of problems that must be resolved simultaneously; but by itself it

MACNELLY
DON'T GET ME WRONG... I'M FOR PROGRESS.... BUT ARE YOUR BACK-UP SAFETY SYSTEMS RELIABLE?.. HAVE YOU ALLOWED FOR HUMAN ERROR?... THEN THERE'S THE PROBLEM OF WASTE PRODUCT DISPOSAL...
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Cycles of pessimism and optimism about material progress and the future of humanity have occurred throughout history. The critical question is whether today's predominating pessimism is justified.

cannot resolve these near-term, non-material constraints.

Issues tend to become confused because these non-material constraints frequently create the same results as actual physical scarcities, at least in limited regions. But we must carefully distinguish between artificially created situations, such as the drop in world oil production during the 1979 revolution in Iran, and truly global, physical limits to population and economic growth, for the two are likely to involve quite different policy approaches and implications.

The issues

We have organized this *Bulletin* around a series of questions inspired by a French schoolchild's riddle: If lilies in a pond double each day and on the 30th day have covered the pond, on what day is the pond half covered? The answer is: on the 29th day.[2] This riddle has been used to suggest that the limits to growth may be surprisingly near. But as an analogy to the world situation, the answer is not obvious. It depends on whether the pond (the world resource base) is expanding in size, and, if so, at what speed; whether there are limits to the expansion of the pond; how near we are to those limits; and whether the lilies (the world's population) and their demand on nutrients in the pond (per capita consumption) continue growing at constant rates until they hit the edge of the pool. In other words, the answer depends on the relative rates of growth in demand for and supply of material and environmental resources, and on whether knowledge about what is happening to supply affects the rate of growth in demand and vice versa. Hence our questions:

1. Are there signs to indicate whether in the past we have been winning or losing the race between growth in demand for material and environmental

resources and growth in supplies of these resources?
2. What is likely to happen to demand in the future? Will its rate of growth speed up, slow down, or remain the same?
3. How far and how rapidly can supply —the size of the pond—expand? Is there an ultimate limit; when is it likely to be reached?

Many of the projections on prospects for the future presented in this *Bulletin* are drawn from a recently completed study entitled *To Choose a Future: Resource and Environmental Problems of the U.S., A Long-Term Global Outlook* (Johns Hopkins Press for Resources for the Future, forthcoming 1980), prepared by Ronald G. Ridker and William D. Watson, Jr. for the Center for Population Research, U.S. National Institutes of Health. The time frame chosen was the period from 1975 to 2025, long enough to capture some of the ultimate consequences of population growth but short enough to allow a degree of confidence in our ability to say something useful about the future.

This study projects that, barring serious disruptions in current trends, the world's population will reach nearly 9.4 billion in 2025 compared to 4.3 billion in 1979, despite declining population growth rates, and that the world's per capita Gross National Product (GNP) might then be as high as $2,600 (in 1971 dollars) compared to $1,000 in 1972. Given these projections, the rate of increase in consumption of nonfuel minerals and energy will decline during the period to 2025, although absolute consumption levels will be vastly greater at the end of the period. When these projections are compared with projections of potential supplies, and when the nature of the difficulties in realizing these supplies is considered, it becomes clear that the problems we face in the next half century are associated less with physical exhaustion than they are with unequal distribution of resources, the security of supply lines and trade, environmental problems associated with high levels of use, and above all, with the transition problems in moving from one resource regime to another in an orderly way.

In the world as a whole there appears to be enough land and water to meet food demands during the next half century. But this land and water—plus the know-how, capital and institutions required for their efficient use—are not distributed in the same way as population. International movements of food will have to grow if per capita consumption is not to fall in regions such as South Asia where food production is already barely keeping pace with population growth.

The situation with respect to nonfuel minerals is similar. We must find substitutes for less abundant resources such as tin, tungsten, and lead, and more ways to use abundant resources like aluminum, cement, and glass. And mechanisms must be found to help countries—especially the poorer nations —cope with the disruptive shifts in the terms of trade that such changes in resource use generally entail.

The world's energy problems are the most serious, difficult, and dangerous of all the resource problems the world faces. We already face balance of payment and security problems so far as petroleum and nuclear power are concerned. During the next 50 years these problems will be compounded by the fact that reasonably priced sources of both petroleum and natural gas will be exhausted. This does not mean that the world must learn to live without liquid and gaseous fuels, but it does mean that ways must be found to acquire these fuels from other sources. Adequate alternatives do exist. Liquids and gases can be produced from coal, shale, tar sands, and vegetation, to mention only the most likely sources to be used. And nuclear power and solar energy (captured by using flat plate collectors, photoelectric cells, biomass, and wind, for example) can be substituted for

liquids and gases in many uses. The problem is to bring these alternatives into use in an orderly, equitable, and safe way—safe both environmentally and militarily.

In all this, a decline in future population growth would be of considerable help, for it would provide the world with more time and resources with which to solve these problems. But whatever future population growth rates may be, the world will still be faced with unsolved problems resulting from past growth. There are no simple explanations or unidimensional solutions for our problems.

We turn now to our first question: What is the record to date in balancing population and economic growth against available supplies?

The Past: Winning or Losing?

For practical reasons, all projections take off from past trends. Therefore, it is useful to start with what has happened so far, even though the future will not replicate the past. Have population and economic growth rates—the two fundamental determinants of demand for material and environmental resources—been outstripping supply? To answer this question, we can look at several kinds of evidence: (1) socioeconomic indicators of levels of material well-being, to tell us whether life has been getting better or worse for most people; (2) changes in relative price levels, which reflect changes in resource scarcity; and (3) indications of improvement or deterioration in the quantity or quality of material or environmental resources.

Socioeconomic indicators show improvement

If we judge by the goals of economic growth, surely the world as a whole has been winning the race, at least to the mid-1970s. By practically whatever measure of basic necessities or material well-being one judges—per capita incomes, calories consumed, shelter and clothing, hours of leisure, protection against physical dangers and major famines, medical care, infant mortality, or life expectancy—the average person in the world today is at least somewhat better off than his parents and substantially better off than his grandparents. Table 1 (page 8) provides data compiled by the World Bank on a few such indicators available on a comparable basis for most countries. As can be seen, even in the poorest of countries there was some progress in practically every indicator between about 1960 and the mid-1970s. In Pakistan, for example, per capita Gross National Product (GNP) increased annually by 3.1 percent compared to 2.3 percent in the U.S.; energy production per capita increased by 6.0 percent per year, compared to 1.9 percent in the U.S.; and life expectancy at birth rose from 42 to 51 years, compared to a rise from 70 to 71 years in the U.S.

But there are problems with this relatively positive assessment. Most important, these improvements are *averages;* they say nothing about what is happening to the *distribution* of material well-being. While there is no evidence that the poor have become absolutely worse off as the averages have increased,[3] there is evidence that they are not advancing as fast as the figures suggest, that their numbers are increasing, and that the gap between the rich and the poor has grown. This may be related to the process of economic growth itself. Income distribution appears to be worst in countries that have progressed to middling levels of per capita income and best in rich countries. For example, in 1956 in India (a low income country), the lowest 20 percent of the population earned 8 percent of total income while the highest 4 percent earned 20 percent. By contrast, in

Table 1. Selected Socioeconomic Indicators: 1960 to 1976

Country	Population (millions) mid-1976	Avg. annual growth (%) GNP per capita 1960-76	Avg. annual growth (%) Energy production per capita 1960-75	Per capita food production 1965/7 = 100 Avg. 1974/76	Life expectancy at birth (years) 1960	Life expectancy at birth (years) 1975	Infant mortality rate 1960	Infant mortality rate 1975	Population per physician 1960	Population per physician 1974	Percent of age group enrolled in school: Primary 1960	Primary 1975	Secondary 1960	Secondary 1975	Adult literacy rate (percent) 1960	Adult literacy rate (percent) 1974
Low income countries	1,215.5	0.9	7.0	96.0	36	44	142	122	37,000	21,185	30	52	2	8	10	23
Bangladesh	80.4	-0.4	—	95.0	39	42	—	140	—	9,350	47	73	8	25	—	23
India	620.4	1.3	1.9	107.0	42	50	139	122	5,800	4,160	41	65	23	29	24	36
Pakistan	71.3	3.1	6.0	114.0	42	51	142	113	11,000	3,970	30	51	11	15	16	21
Indonesia	135.2	3.4	6.2	117.0	40	48	82	—	41,000	18,160	67	81	6	18	47	62
Middle income countries	894.8	2.8	5.8	104.0	49	58	72	46	3,050	2,430	79	97	12	35	61	63
Nigeria	77.1	3.5	27.0	89.0	34	41	207	163	32,000	25,440	36	49	3	10	25	—
Brazil	110.0	4.8	4.2	114.0	56	61	70	—	3,600	1,660	95	90	11	18	61	64
Industrialized countries	683.8	3.4	2.1	110.0	70	72	25	15	860	650	108	104	53	83	—	99
Japan	112.8	7.9	-5.1	107.0	67	73	31	10	920	870	103	100	74	95	98	99
United States	215.1	2.3	1.9	114.0	70	71	26	16	780	610	118	104	64	91	98	99
Capital surplus oil exporters	12.2	7.0	8.7	—	45	53	—	—	5,800	1,140	59	90	9	45	—	—
Centrally planned economies	1,207.7	3.5	3.6	114.0	66	70	—	—	830	480	100	99	47	62	—	—
China, People's Rep.	835.8	5.2	3.0	108.0	51	62	—	—	—	—	—	—	—	—	—	—
U.S.S.R.	256.7	3.8	4.7	113.0	68	70	—	—	520	340	100	99	73	71	98	99

Source: The World Bank, *World Development Indicators*, June 1978

1960 in Brazil (a middle income country), the lowest 20 percent earned only 3.5 percent of national income, while the upper 4 percent earned 38.4 percent. But in 1969 in the U.S., the lowest 20 percent earned 5.6 percent of total income and the highest 4 percent earned 14.8 percent.[4] In the study on which this finding is based, Taiwan and South Korea were found to be the only major developing countries to have experienced a steady improvement in income distribution along with rapid economic growth. The centrally planned economies of Yugoslavia, Cuba, and the People's Republic of China are the only other exceptions.

The same is true between countries. While developing countries are in general materially better off today than they were two decades ago, the gap between rich and poor countries has undoubtedly widened. For example, in 1960 per capita income in Pakistan was $104 while that of the U.S. was $5,484. In 1976, even though Pakistan's per capita income had grown more rapidly than that of the U.S. in the interim (3.1 versus 2.3 percent per year), the levels were $170 and $7,890, a gap between the two countries some $2,000 greater than in 1960.[5]

This growing gap between developed and developing countries is due in large part to the much more rapid population growth in developing countries, which has greatly reduced the benefits of economic development. Table 2 illustrates this with regard to food production. From 1961 through 1975, the annual rate of increase in food production in developing countries was greater than that in developed countries, but because of more rapid population growth, per capita production grew much more slowly. Per capita food production in

Table 2. Annual Rate of Increase in Food Production in Relation to Population: Developed and Developing Regions, 1961 to 1975

Region	Food production		Population		Increase in food production per capita	
	1961-1970	1971-1975	1961-1970	1971-1975	1961-1970	1971-1975
	(Percent per year)					
Developed regions						
North America	2.4	1.9	1.3	0.9	1.1	1.1
Western Europe	2.3	1.9	0.8	0.6	1.5	1.3
Oceania	3.4	1.3	1.9	1.7	1.5	0.7
Eastern Europe and U.S.S.R.	3.2	2.1	1.0	0.9	2.2	1.1
Total	2.7	2.0	1.1	0.9	1.6	1.2
Developing regions						
Africa	2.9	0.5	2.5	2.7	0.4	-2.1
Latin America	3.0	2.7	2.8	2.7	0.3	-0.1
Far East	2.7	2.8	2.5	2.5	0.2	0.3
Near East	3.3	3.7	2.7	2.8	0.7	0.9
Asian centrally planned economies	2.8	2.4	1.7	1.7	1.1	0.7
Total	2.9	2.5	2.3	2.3	0.6	0.2

Source: Food and Agricultural Organization (FAO), *Billions More to Feed* (Rome: FAO, 1976) p. 8

1971-75 actually declined in Africa and Latin America, the regions with the highest annual population growth rates in this period (2.7 percent). Another illustration is provided by the case of the Aswan Dam in Egypt. When completed in 1970, the dam increased the country's arable land by a third (800,000 hectares). But because of population growth during the decade it took to build the dam, from 26 to 33 million, food output per capita has hardly improved at all. The gains made in literacy provide a final example. More people are literate than ever before in human history and, worldwide, the proportion of illiterate adults dropped from 44 to 32 percent between 1950 and 1975. Nonetheless, the absolute numbers of illiterate adults have also increased during this quarter century from 700 to 800 million.[6]

Another difficulty with the picture presented in Table 1 is that the world may be achieving these gains in average well-being at the expense of future generations. This would be the case if this generation is using up the world's resource base or environmental carrying capacity faster than new discoveries and technology can expand them. Thus, while it is useful to know that life has been improving for the majority of humanity, this fact tells us nothing about the future. For that we must turn to other indicators.

Past trends in market prices

A better, though far from perfect, way to judge whether resources have become more scarce—that is, whether demands for resources have grown faster than new discoveries and technological changes can provide them—is to observe what has happened to resource prices. If resources have become more scarce, their prices, relative to those of other goods, should have risen.

The most comprehensive and well-known study of historical trends in natural resource prices, *Scarcity and Growth*, by Harold Barnett and Chandler Morse, showed for the U.S. that average prices of most raw materials fell or remained stable in real terms between 1870 and 1957, despite the fact that ores with steadily lower concentrations of minerals were being mined.[7] This was the result primarily of technological advances in mining and processing and sharp declines in the costs per unit of output of labor, capital, and energy. Earl Cook describes the story with respect to copper and the per unit cost of energy used to mine it:

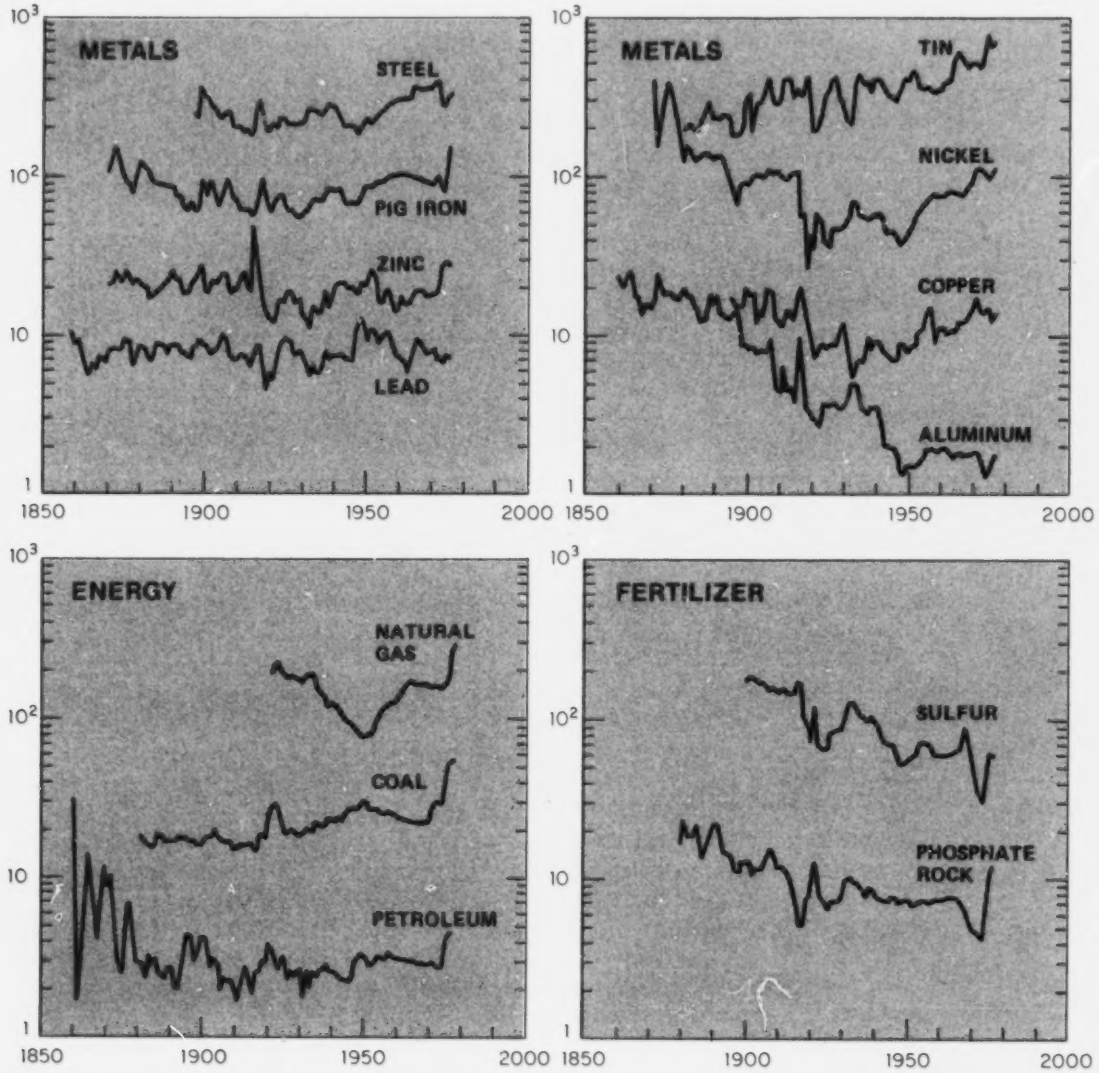
> "In 1900 the lowest grade of copper ore economically minable was about 3 percent; today [1976] the economic cutoff has fallen to about 0.35 percent; at that grade each ton of refined copper produced requires the breaking, transport, and milling of almost 300 tons of rock and, in addition, the removal of perhaps an equal amount of waste or barren rock. A great deal of energy —about 26,000 kilowatt-hours, the equivalent of the energy in about 4 metric tons of Wyoming coal—is required to produce a metric ton of copper today, but the cost of that energy is still low compared to the cost of supporting the equivalent in men and mules."[8]

While more recent studies have qualified the findings of Barnett and Morse, they generally show that at least until 1970 the prices of most major raw materials in the U.S. were no higher in real terms than they had been many decades earlier.[9] This is seen in Figure 1, which displays trends in relative or constant dollar prices (1967 dollars) for eight major metals; for natural gas, coal, and petroleum; and for sulfur and phosphate rock, major components of fertilizer. The graphs do, however, show sharp upturns for some items in the 1970s, particularly for energy and the components of fertilizer.

While prices are better than any other signals of scarcity, they are far from perfect. It is tricky to obtain good measurements of the most appropriate prices and to separate out the effects of inflation, short-run fluctuations, and changes in market regulations and controls. For example, in recent years the

Figure 1. Price Trends for Selected Major Resources: U.S., 1870 to 1977

(Relative prices in constant dollars)



Source: Ulrich Petersen and R. Steven Maxwell, "Historical Mineral Production and Price Trends," *Mining Engineering*, Vol. 31, No. 1 (January 1979), pp. 30 and 31.

Note: For details on converting these prices in terms of 1967 dollars, see the above source.

Organization of Petroleum Exporting Countries (OPEC) has raised world petroleum prices to levels above what they would have been in free markets, while U.S. government regulations have kept domestic energy prices below appropriate world levels. (The shortages caused by production shortfalls during the Iranian revolution have led to the reverse situation in the last few months, with spot market prices rising above "benchmark" prices.)

But the most fundamental problem is that prices exist only for goods traded

in markets. Thus, changes in environmental quality and the use of resources like air and water cannot be judged in this way. Indeed, since such environmental resources typically are implicitly priced at zero, the costs of producing raw materials—which generally use disproportionately large amounts of such resources—tend to be biased downwards. Further, prices of raw materials often do not include the costs of cleaning up the pollution incurred in their production. Where more or less effective environmental regulations exist, as in the U.S., businesses typically do have to pay much of the cost of cleaning up the pollution that their production processes generate. But the cost of cleaning up damages occurring before effective regulations were present are typically borne by the whole population in the form of higher taxes. And globally, of course, effective regulation is more the exception than the rule.

Another difficulty is that such market prices may not give adequate weight to the interests of future generations.[10] We leave a heritage of slowly or never-degrading pollutants to our descendants, whose interests are not reflected in the price signals being given producers. Moreover, markets—and those who regulate them—are short-sighted; they often fail to stimulate development of technologies that will be needed relatively far in the future but which require long lead times to bring into production. For example, a serious consequence of keeping the price of petroleum and natural gas in the U.S. below world levels has been the failure to provide adequate incentives to conserve and to search for and develop substitutes in a timely fashion. In addition, problems such as the removal of topsoil through erosion and the buildup of carbon dioxide in the atmosphere might not have economic consequences that affect prices until it is very difficult, expensive, or impossible to deal with them. The health costs that future generations will have to bear because of today's pollution emissions are similarly not reflected in today's market prices.

Specific evidence of depletion

If measures of well-being and market prices are not adequate to reveal if we have been winning or losing the race between demand and resources, the only alternative is to look at what is happening to specific material or environmental resources, to see if there is widespread evidence of depletion in stocks or deterioration in quality. The problem with this approach is that there are no overall, quantitative indexes. Examples of deterioration can be found, but it is difficult to say whether they are omens of approaching global overload or manifestations of transitional, localized, or manageable problems. Examples of improvement can also be found, but it is nearly impossible to strike a balance between them and signs of deterioration. The best we can do is to try to clarify the nature of the confusing situation we face in several important areas.

Renewable biological resources. Recent trends in per capita production of various biological resources have been cited as evidence that human numbers have arrived at the limits of the earth's carrying capacity. A number of these trends are presented in Figure 2 (page 14). A general decline *might* signal the approach of physical limits, but the specifics of each case must be considered before drawing conclusions.

Worldwide per capita production of beef did indeed decline for two years in a row in 1977 and 1978, but this is hardly enough evidence to argue that the trend will be downward from this point on. As can be seen, similar fluctuations have occurred since 1960. Per capita production has also declined for mutton since 1972 and for wool since 1960. But these two trends are related to changes in taste and the development of synthetic fibers which have made it less profitable to raise sheep and supply mutton. If tastes and technologies were to change

again or synthetics were to become more expensive relative to the cost of raising sheep, these trends could be reversed.

For wood, the trend in per capita production is clearly downward. Indeed, forestry products are an exception to the general finding of Barnett and Morse that raw material prices have not risen during the last century. Twenty-five years ago forests covered a quarter of the world's land surface. Today they cover only one-fifth and, if present trends continue, the fraction could fall to one-sixth in 2000 and one-seventh in 2020.[11] Most of this deforestation is occurring in developing countries where energy price rises and population growth are intensifying pressures on fuelwood and timber supplies, especially in the delicate ecosystems of tropical forests.

Fisheries, too, are probably overexploited and declining at this time. From 1950 to 1971, the world's total fish catch rose by 5 to 6 percent a year, from 21 million metric tons annually to a peak of just over 70 million metric tons. Production then dropped abruptly to less than 66 million tons in the next two years and has fluctuated generally downward since then. With growing world population, the drop in per capita yields has been even greater. While some nontraditional marine species such as krill could be exploited further, especially for livestock feed, most analysts agree that the traditional fish population is not sustainable without some cutback in the catch. If ocean pollution grows over time, consumption will have to be reduced even further to protect the fish population, though there are no good numbers to indicate the magnitudes involved. The same holds for freshwater fisheries. Inadequate international cooperation has hampered management of ocean fisheries and control of ocean pollution, although the on-going United Nations Law of the Sea Conference offers some hope of correcting this situation.

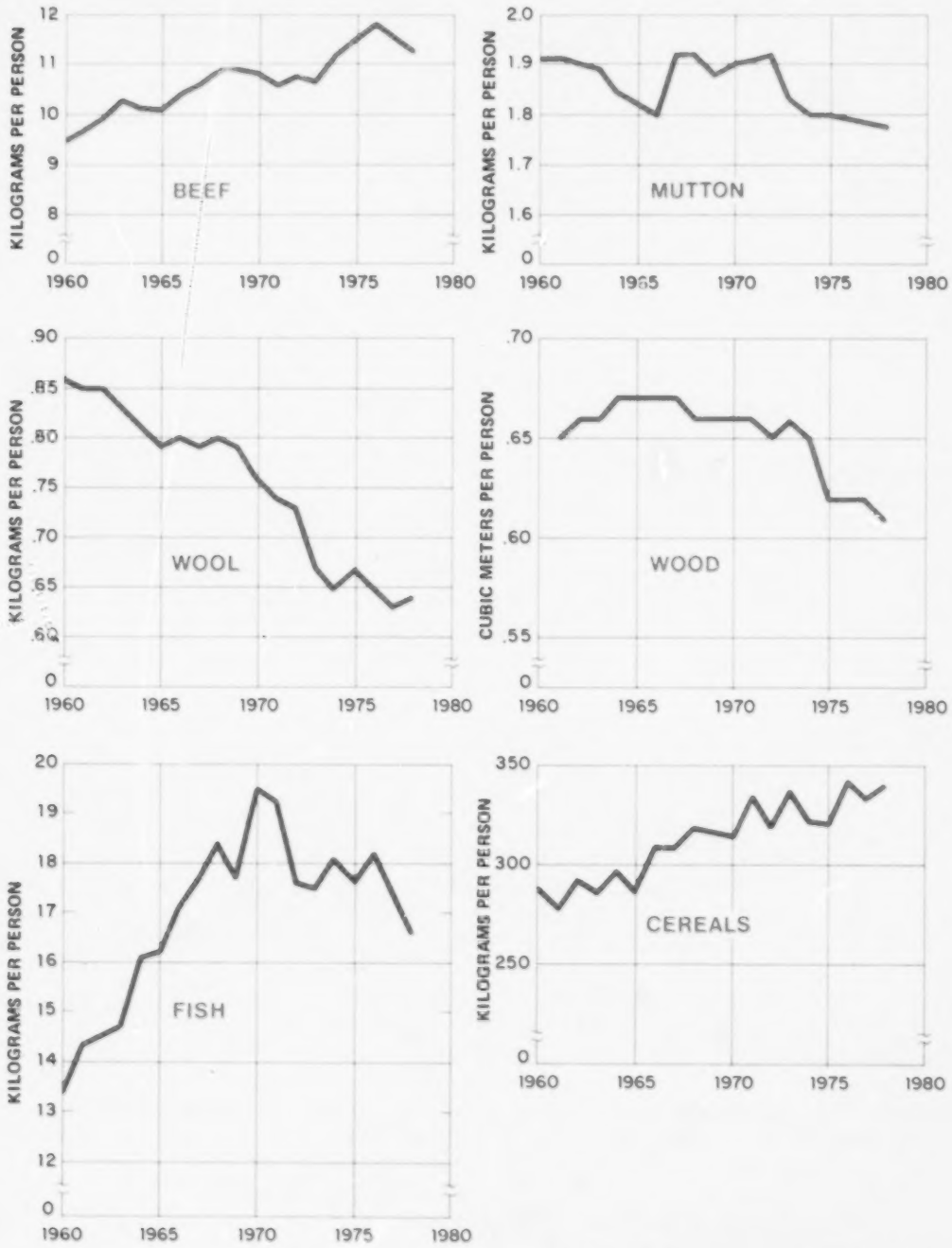
But production technologies are changing dramatically in forestry and fishing. Unlike modern agriculture, these industries were still in the hunting and gathering stage a few years ago. But increasingly, settled farming techniques are beginning to be applied. The change is most marked in the forestry sectors of developed countries. Land in forests in the U.S. has been approximately stable since 1920, despite significantly increased urbanization, and net annual wood growth nearly quadrupled between 1920 and 1977, primarily due to higher yields per acre.[12] In developing countries the situation is far more serious because of encroachments on forest land for other uses and the inability of the extremely poor to wait for trees to grow to optimal size before cutting. But even here isolated examples of successful reforestation and village woodlot programs can be found.[13]

The fishing industry is somewhat further behind in applying farming techniques, in large part because the technological problems are more difficult to solve. But research and commercial efforts in this area are increasing rapidly. Experts see fish farming supplying 15 percent of total U.S. seafood con-

Photo: Government of Malaysia

An example of successful reforestation in Malaysia.

Figure 2. World Production Per Capita of Some Renewable Resources: 1960 to 1978



Source: Lester R. Brown, *Resource Trends and Population Policy: A Time for Reassessment*, Worldwatch Paper No. 29 (Washington, D.C.: Worldwatch Institute, May 1979) Table 1.

sumption by 1982.[14] The potential contribution of fish farming to the scanty protein in Third World diets is still more significant. The Food and Agriculture Organization estimates that, with adequate assistance, management, and control of pollution, fish farming in ponds, rice paddies, and marshes—an ancient and widespread tradition in China and other parts of Asia—could boost inland fishery production worldwide to 50 million metric tons in 2000. Fish farming in saltwater lagoons and estuaries, as now done with young salmon in Japan and the U.S., could be similarly encouraged, provided that the growing pollution of inshore waters can be controlled.[15]

Indications that the rate of growth in per capita production of cereals has declined since 1971 is sometimes taken as another piece of evidence that population growth is pushing against the earth's sustainable biological limits. If true, the situation is serious, for these cereals—wheat, rice, corn, and other grains—directly supply over half the food energy of the world's population and much of the remainder indirectly when consumed as livestock products and alcoholic beverages.

But one's impression of the situation depends on the dates chosen. In the last panel of Figure 2, if one were to draw trend lines starting in 1972 or in 1970 or 1960, it would not be all that clear that data for recent years depart significantly from the upward trend of the 1950s and 1960s. From 1950 to 1971, total world cereal production nearly doubled and per capita production climbed over 30 percent from 251 to 335 kilograms per year. However, losses have been matched by recoveries since 1971, with per capita production actually climbing to a record high of 342 kilograms in 1976,[16] which suggests that it is too early to predict a steady decline from now on.

Between 1950 and 1975 the world's total cropland was extended through irrigation, reclamation, and the conversion of forests, pasture, and rangeland. But these new lands are likely to be less fertile than cropland that has been in use for some time. Moreover, the land lost to urbanization, desertification, and other uses is sometimes above average in fertility. In the U.S., for example, the Environmental Protection Agency has estimated that between 1967 and 1975, 24.3 million acres of cropland were converted to urban and builtup areas and to water uses, and another 54.9 million acres went out of production for other reasons. At the same time, 48.7 million acres of cropland were added, mostly derived from pasture and rangeland. But prime cropland has made up a disproportionate share of the losses to urban and builtup areas while the quality of pasture and rangeland added has been below average.[17]

One can also point to the food shortages of the mid-1960s and early 1970s as evidence of net loss; but these shortages were the result not of global shortages of land or water but of regional droughts, questionable policies, and the absence of global contingency plans to cover lean periods. While droughts were slashing yields in Africa and Asia, American farmers were still being encouraged to withhold land from production; the Argentine government was discouraging production and export by holding domestic wheat prices below world levels; and the Soviet Union suddenly decided to import grain rather than cut back on demand as it had previously done after a poor harvest. Many people have advocated the development of a global reserve of food grains to see the world through such periods, but to this day such a reserve has not been established.

In large measure, the crux of the current problem is unequal distribution of productive capacity and purchasing power. Even with the potential for surplus production elsewhere in the world, the poor countries simply cannot afford to buy adequate quantities of food

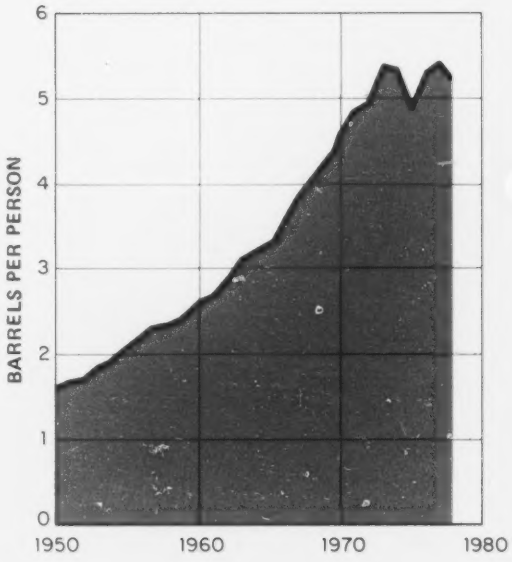
grains in international markets when their own supplies fall short.

Petroleum. As Figure 3 indicates, the steep climb in world oil production per capita appeared to break dramatically in 1974, and without further evidence one might be inclined to predict a downward trend from now on. The quadrupling of oil prices by OPEC in late 1973, from $2.59 in January 1973 to $10.95 in January 1974, (plus the further increases to approximately $20 a barrel in the first half of 1979), can also be taken as signals of coming shortages. But this picture must be tempered by two factors.

First, a more reasonable explanation for the stagnation in per capita oil production since 1973-74 is that the fourfold price rise constrained per capita consumption (which, apart from inventory accumulation, is equal to per capita production). This difference in intepretation is significant. If the figures after 1973-74 result from depletion of petroleum reserves, per capita production (and hence consumption) is likely to turn steadily down. But if they result from shifts in market power that permitted a unilateral price hike by a major group of producers, the future trend is likely to be flat for a few more years as price-induced conservation efforts take hold and then begin rising again, perhaps a bit more slowly than in the past—unless, of course, oil prices begin again to rise faster than the rate of inflation.

The latter interpretation seems closer to the mark. What appears to have happened—at least in part—is that depletion of working fields in many parts of the world plus discoveries in the Middle East led to concentration of production in the hands of a small group of countries who, for political as well as economic reasons, were able to band together to raise the price. With development of oil fields in Mexico, China, and other developing countries, and in the North Sea, Alaska, and possibly also the Soviet Union, major producers

Figure 3. World Oil Production Per Capita: 1950 to 1978



Source: Lester R. Brown, *Resource Trends and Population Policy: A Time for Reassessment*, Worldwatch Paper No. 29 (Washington, D.C.: Worldwatch Institute, May 1979) Figure 2. Reproduced with permission.

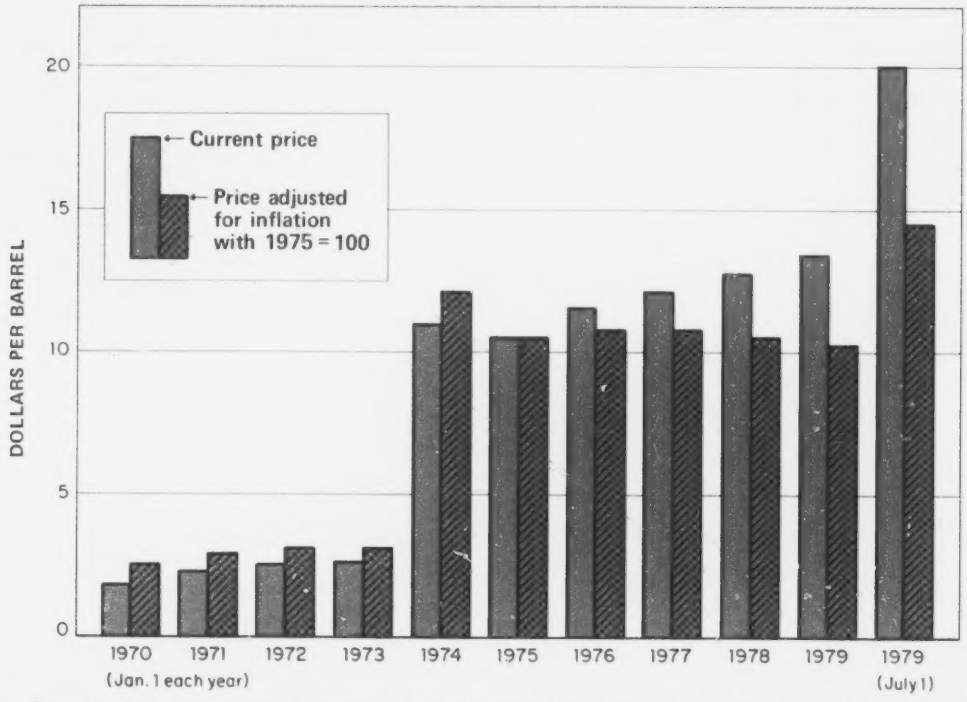
may find it more difficult to act in concert for a time. Eventually, as remaining petroleum resources are drawn down, production could become concentrated again, but not necessarily in the same countries that dominate today's markets.

Second, contrary to what many people appear to believe, the world price of oil, properly corrected for inflation, did not rise much between 1974 and 1979. As Figure 4 indicates, from January 1, 1974, to January 1, 1979, the quoted world price increased from $10.95 to $13.34 a barrel. But other prices rose even more so that on a constant price basis the cost of acquiring a barrel of petroleum actually fell. For the U.S. this fall was about 15 percent; for West Germany, which benefited from the devaluation of the U.S. dollar (the currency required by OPEC in payment for oil), the fall was 29 percent. The shortfall in Iranian production caused by that country's political turmoil has permitted

OPEC to catch up during the first half of 1979, and in June the price was officially raised to approximately $20 a barrel. Corrected for U.S. inflation, this amounts to a 40 percent rise in six months; but it is only a 20 percent increase over the January 1974 price, as demonstrated in Figure 4. Continued inflation and further depreciation of the dollar could wipe out much of this increase if the price is not raised again before the end of 1979. (Note that this discussion pertains to the cost of purchasing petroleum in the world market. The price to U.S. consumers has risen faster in recent months because of efforts to decontrol domestic prices, to allow them to rise to world levels.)

Thus, it cannot be taken as self-evident on the basis of price trends since 1974 that international oil prices are going to rise faster than inflation during the next few years. So long as this is the case, the decline in per capita production (and consumption) that occurred after the dramatic price rise of late 1973 cannot be taken as a sign that the trend is clearly downward from here on. There are indeed very serious dangers in the current world energy situation, but they stem from the fact that importing countries have become increasingly dependent on supplies from a politically unstable area of the world, not from the growing likelihood of imminent exhaustion.

Figure 4: International Oil Prices, Current and Deflated Dollars Per Barrel: January 1970 to July 1979



Source: Ronald G. Ridker and William D. Watson, Jr., *To Choose a Future: Resource and Environmental Problems of the U.S., A Long-Term Global Outlook* (Baltimore: Johns Hopkins Press for Resources for the Future, forthcoming 1980).

Note: **Current price** through January 1979 is for benchmark or marker light oil sold by Saudi Arabia. The July 1979 current price shown is roughly the midpoint of the benchmark price of $18 and the maximum of $23.50 agreed to at the June 1979 meeting of the Organization of Petroleum Exporting Countries (OPEC). Actual market prices can vary substantially. **Deflated price** is the current price adjusted for inflation, using the U.S. GNP deflator, with 1975 = 100.

Environment. Environmental quality might appear to be one area where deterioration on a global scale is indisputable. Pressure on the environment has indeed increased with economic and population growth. But even here the evidence is mixed.

In any country where pollution regulations are taken seriously, there has been measurable improvement in levels of such mass pollutants as carbon monoxide, particulates, hydrocarbons, sulfates, and suspended solids in water. In the U.S. for example, the Council on Environmental Quality reports that between 1973 and 1976 annual carbon monoxide emissions dropped from 81.3 to 69.7 million tons, or 14.3 percent, as automobile emission controls were enforced in the wake of the Clean Air Act of 1970.[18] But the U.S., like other rich countries, can afford to trade off some economic growth for environmental quality. In most developing countries, safeguarding the environment has so far generally taken second place in the struggle to upgrade living standards. In the short run, food and jobs are more important than wilderness protection or even some health losses due to air and water pollution. This could be shortsighted; prevention is typically cheaper than abatement and cleanup after pollutants are released, and some kinds of pollution can seriously affect production capacity. But this approach is understandable, given the more immediate problems these countries face.

There are other growing environmental problems that no country is yet controlling, in part because methods of economic control are not always known. These include cancer-causing substances released by the burning of fossil fuels, highly toxic trace substances with long half-lives like arsenic, lead, certain pesticides and herbicides, and radioactive pollutants, all of which can concentrate into lethal doses as they move through food chains. And still others such as the buildup of carbon dioxide in the atmosphere are not being controlled because of uncertainty about how serious they really are. Environmental problems like these may be our most threatening legacy from past population and economic growth. We return to them at the end of the *Bulletin*.

The answer?

Clearly, the evidence to answer our first question regarding the balance to date between demand and supply is inconclusive. There are signs of deterioration in the global resource position, but there are also signs of improvement. Some solutions have been found; others have not, or have not been implemented. But considering the fact that welfare indicators have been improving on average; that relative prices of most resources, at least until the 1970s, were no higher than in earlier decades; and that consideration of specific bits of evidence about resource and environmental change is on the whole inconclusive, we are left with at least a weak presumption in favor of the proposition that the world as a whole has been winning the race between growth in demand and supply of resources. But with all the qualifications involved it is a very weak presumption and, more importantly, provides no solid basis for predicting the future—a future that may be substantially different from the past.

Future Demands

This leads to our second question: What is likely to happen to the rate of growth of demand for resources? To answer, it is important to distinguish between rates of growth in population (the lilies in the pond) and rates of growth in per capita demand for various resources (how much each lily consumes of nutrients in the pond), and between rich and poor countries.

Population projections

In more developed, rich countries, rates of natural increase (births minus deaths)

Table 3. Average Annual Rates of Population Growth, 1950 to 1980, and Selected Projections to 2000

Region	1950-55	1955-60	1960-65	1965-70	1970-75	1975-80	Projected 1995-2000
			(Percent)				
World	1.8	2.0	2.0	1.9	1.8	1.8	1.34 - 1.70
More developed	1.3	1.3	1.2	1.0	0.9	0.8	0.45 - 0.60
Less developed	2.0	2.3	2.4	2.3	2.2	2.2	1.62 - 2.00
Africa	2.2	2.4	2.5	2.6	2.7	2.9	2.51 - 2.83
Asia	—	—	—	—	—	—	1.36 - 1.80
East Asia	1.8	2.0	1.9	1.8	1.6	1.3	—
South Asia	1.8	2.2	2.4	2.5	2.4	2.5	—
Latin America	2.7	2.8	2.8	2.7	2.6	2.7	1.92 - 2.40
North America	1.8	1.8	1.5	1.1	0.9	0.8	0.37 - 0.65
Europe	0.9	1.0	1.0	0.9	0.8	0.6	—
U.S.S.R.	1.7	1.8	1.5	1.1	0.8	0.9	—
Oceania	2.2	2.2	2.1	2.0	1.8	1.5	—

Sources: Data for 1950-80 from United Nations, Population Division, "Demographic Estimates and Projections for the World, Regions, and Countries as Assessed in 1978," provisional report, January 25, 1979. Projections for 1995-2000 from Community and Family Study Center of the University of Chicago, World Bank, United Nations, and U.S. Bureau of the Census, reported in Amy Ong Tsui and Donald J. Bogue, "Declining World Fertility: Trends, Causes, Implications," *Population Bulletin*, Vol. 33, No. 4 (Washington, D.C.: Population Reference Bureau, October 1978) Table 14.

have already declined to within striking distance of zero. By 1977, they were actually at or below zero in five countries—the United Kingdom, Austria, East and West Germany, and Luxembourg.[19] The rates could rise again, but considering that the decline is associated with increased female labor force participation and other changes in sexual roles which tend to reduce fertility and which are not likely to be reversed, whatever rise occurs will probably be small and temporary.

Population growth rates appear to have leveled off in the poor, less developed countries as a whole (Table 3). They have fallen significantly in many Asian countries and in a few in Latin America, although almost nowhere in Africa. While a slowdown in declines in death rates accounts for part of this, the more important component has been the beginning of declines in birth rates. In India, Thailand, the Philippines, Indonesia, and Colombia, for example, birth rates are currently estimated to be in the middle to low 30s (compared to 15 in the U.S.), and as low as 24 in South Korea and perhaps 20 per 1,000 population in China. For all these very populous countries, this represents a decline of at least 14 percent since 1965.[20] If the material and social progress of recent years is not reversed and if family planning programs are pursued with no less vigor than they now are in many developing countries, the world's population growth rate is likely to fall, slowly and grudgingly, from this point on. The last column of Table 3

suggests the range within which it might fall by the year 2000. The decline is not so fast as one might hope for, but is better than that projected by the United Nations in the early 1970s.[21]

This decline in the rate of increase is not sufficient to reduce the absolute size of the additions, however. Even the reduced rate of 2000 will translate into some 97 million additional people annually according to the current U.N. "medium variant" population projections[22]—up from an annual increment of about 73 million in the late 1970s. The U.N. medium variant projection of 1978 puts the total global population at 6.2 billion in 2000 (compared to 4.3 billion in 1979) and about 11.5 billion when births and deaths ultimately come into balance and human numbers stop increasing, somewhere about 2075.[23] Thus, even though the *rate of growth* in demands for the earth's resources represented by numbers of people will ease, the sheer *size* of those numbers will still place increasing pressures on material and environmental resources for a long time to come.

Growth in per capita demand

Per capita demands for material goods in poor countries are likely to expand as fast as growth in their incomes permits —which is likely to be faster than growth rates in rich countries, especially since most of the developing countries are just beginning to industrialize, mechanize agriculture and so on—the most resource-intensive phase of modernization. But their incomes are still so low that their demands for resources will not weigh very heavily in total world consumption for some time to come. While less developed countries contain 73 percent of the world's 4.3 billion people in 1979 and will comprise 78 percent of the 6.2 billion now projected for 2000, they currently account for only 20 percent of the world's output of goods and services, and that percentage is not likely to rise to more than 23 percent by 2000.[24]

Of more importance for resource requirements is what happens in rich countries. The best conjecture here is that growth in demands for (and consumption of) material goods will slow down significantly. This is because the rate of growth in per capita incomes is likely to fall and because a declining fraction of income is typically spent on material goods as incomes rise. The slowdown in the rate of labor productivity, and hence income, in developed countries is already under way. It is likely to continue for a variety of reasons, including increasing investments for new forms of energy, environmental controls, additional health and safety requirements, and more of what is sometimes called on-the-job leisure—a willingness to work but only at a more relaxed pace as incomes rise.

Then, too, the quantities of material goods which people demand are likely to rise at a decelerating rate as incomes continue to rise in developed countries. (*Expenditures* may continue to rise with incomes as people purchase more luxurious or sophisticated items, but our concern here is with resource requirements, which are more closely related to the number of units purchased.) This deceleration is partly related to the quantities of goods already possessed. There are just so many cars, refrigerators, and houses that one individual can conveniently own; at some point in the accumulation process he will find that he does not have the time to use and enjoy them. For well established goods like cars and refrigerators, diminishing returns to the possession of more than one or two sets in very quickly; and new goods coming on the market must compete with other possessions for the individual's time, with the likelihood that some possessions will be shoved aside. These diminishing returns are also related to the quantities of goods possessed by others. If I accumulate material goods faster than others do, I feel

better off. But if others accumulate at the same rate, my enjoyment may diminish. For some goods like jewelry and designer dresses, snob appeal explains this phenomenon, but for most it is simply a matter of congestion. I cannot enjoy my car (or snowmobile or secluded vacation site) as much when everyone else is trying to do the same.[25]

Putting all these factors together leads to projections of rates of growth in demands for resources that decline significantly over the coming decades. Table 4 (page 22) presents projections of consumption from the Ridker-Watson study referred to earlier which cover the period from 1971 to 2025 for nonfuel minerals and from 1975 to 2050 for energy. As can be seen, they indicate that the growth in total world consumption of energy will slow from 4.6 percent per year in 1975 to 3.6 percent in 2000 and 3.0 percent in 2025. For most nonfuel minerals shown, annual growth rates in total consumption are similarly lower in the 2000-2025 period than they are in the 1971-1985 period.

These projections probably underestimate the slowdown that will occur because they are based on older population projections than those used in Table 3. For example, the U.N. medium variant projection for the world's population in 2000 is now 6.2 billion, as noted, rather than the 6.4 billion used in the projections of consumption in Table 4. The energy projections may not allow sufficiently for conservation which, given appropriate monetary incentives or government regulations, could result in a significant saving. The projections for nonfuel minerals are also likely to be on the high side because they represent demands on virgin materials and assume that recycling—which does not draw on primary resources—will supply the same fraction of total demand that it did in 1973-74, an unlikely occurrence given probable changes in prices, policies, and technologies. In addition, they include only a few of the substitutions likely to occur between less abundant materials (like metals) and more abundant materials (like cement and glass).

There will also be changes in the mix of resources consumed, as seen for energy in Table 4 and Figure 5 (page 23). In the scenario of the Ridker-Watson study used here, it was found that the most important source of energy in 1975—petroleum, which then accounted for 42 percent of commercial energy consumption—would drop to third place by 2025, tied with natural gas, each accounting for 18 percent of the total. By 2050 both would have virtually disappeared. Coal, increasingly used in the form of synthetic liquids and gases, is projected to become the leading source of energy by 2025, although its share of the total in 2050 (36 percent) will not be much above what it was in 1975 (30 percent). These projections assume that nuclear energy will continue to develop and will account for 23 percent of consumption in 2025 and 30 percent in 2050. If public resistance to nuclear reactors continues unabated, these projections will be too high. The percentage contributed by solar energy remains low until after 2025 because this scenario assumes no significant technological breakthroughs or changes in relative costs until after 2000. Needless to say, government subsidies or tax incentives could be used to speed up the development of solar energy and synthetic fuels. Policies that move in this direction have now been formulated in the U.S.

As development advances, the developing countries' share of world commercial energy consumption is projected to grow from 16 percent in 1972, when they accounted for 71 percent of world population, to 47 percent in 2025 when they will comprise 85 percent of global numbers, as seen in Table 5 (page 23). The U.S. share of world energy consumption is also projected to come more into line with its population. In 1972, with just over 5 percent of the world's population, the U.S. consumed 32 per-

Table 4. World Consumption and Rates of Growth in Consumption of Selected Resources: 1971 to 2050

Nonfuel minerals

Resource	Absolute consumption (1,000 short tons) 1971	Annual rate of growth in consumption (%) 1971-1985	1985-2000	2000-2025
Aluminum	12,107	6.7	4.8	4.4
Chromium	3,416	2.5	2.5	2.6
Cobalt	44	4	2.9	3.2
Copper	8,026	2.9	2.1	2.1
Iron in ore	456,183	2.3	2.2	2.3
Lead	4,768	3.1	2.7	2.5
Manganese	2,786	6.0	3.6	3.7
Molybdenum	40	7.4	3.4	3.3
Nickel	657	4.7	3.6	3.5
Phosphate rock	114,913	3.2	2.6	2.0
Potash	21,711	2.8	2.2	1.9
Sulfur	24,251	4.5	3.6	2.9
Tin	257	3.1	2.6	2.8
Titanium	543	9.2	4.5	3.7
Tungsten	23	4.9	2.9	3.1
Vanadium	22	4.7	3.4	3.0
Zinc	5,525	3.3	2.6	2.7

Energy

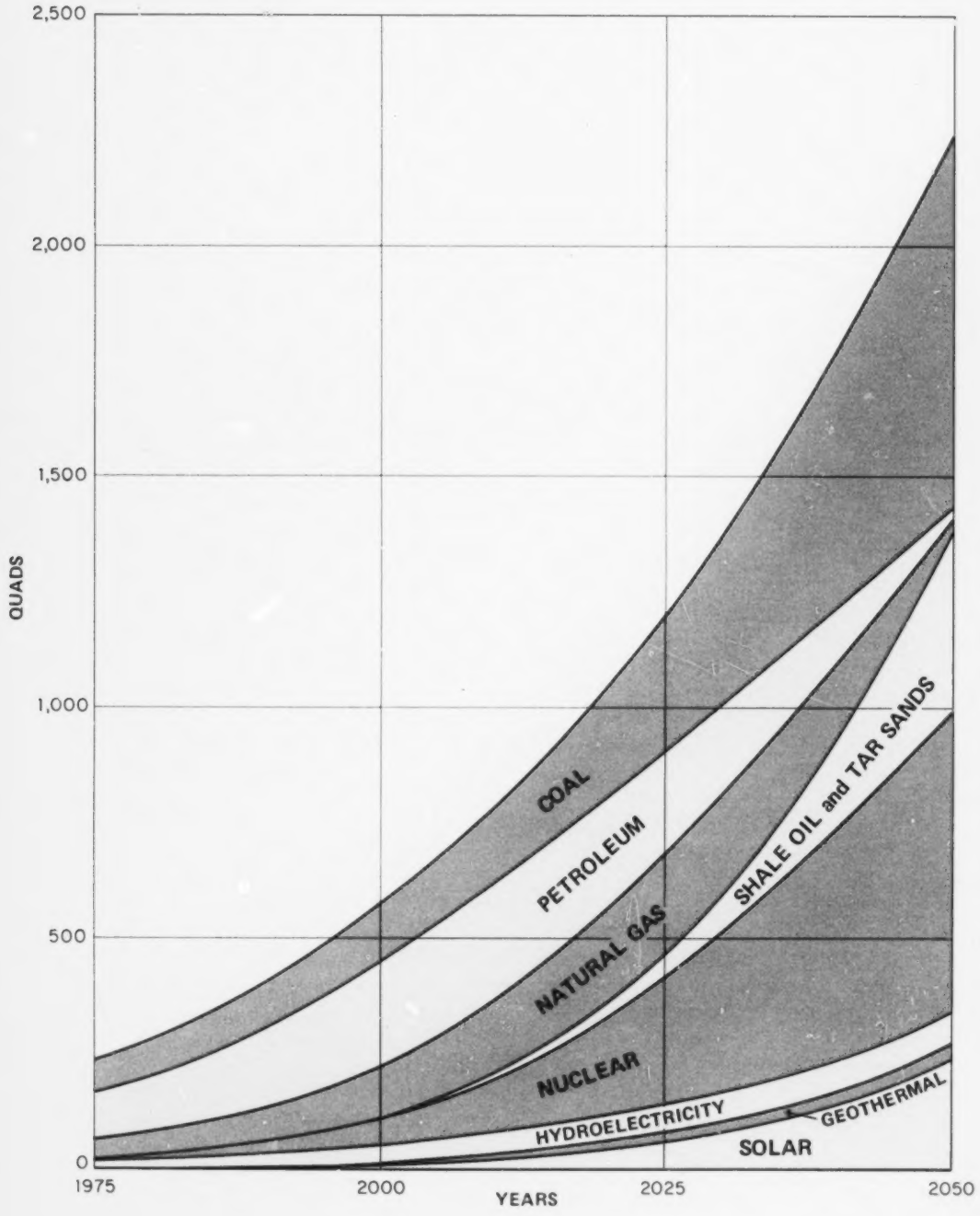
	1975		2000		2025		2050	
	Quads[a]	(%)	Quads	(%)	Quads	(%)	Quads	(%)
Coal	70	(30)	125	(22)	292	(24)	806	(36)
Petroleum	100	(42)	222	(39)	217	(18)	26	(1)
Natural gas	48	(20)	118	(21)	221	(18)	27	(1)
Shale oil and tar sands	0	(0)	—	(—)	50	(4)	378	(17)
Nuclear	3	(1)	58	(10)	276	(23)	666	(30)
Hydroelectricity	16	(7)	41	(7)	63	(5)	69	(3)
Geothermal	—	(—)	4	(1)	22	(2)	32	(1)
Solar	—	(—)	6	(1)	60	(5)	237	(11)
Total	237	(100)	574	(100)	1,201	(100)	2,241	(100)
Annual rate of growth (%) in total (from previous year)	4.6		3.6		3.0		2.5	

Source: Ronald G. Ridker and William D. Watson, Jr., *To Choose a Future: Resource and Environmental Problems of the U.S., A Long-Term Global Outlook* (Baltimore: Johns Hopkins Press for Resources for the Future, forthcoming 1980).

[a]One quad of energy equals 10^{15} British thermal units. This much energy could be provided by 172 million barrels of oil or 37.8 million metric tons of coal.

Note: These projections are based on the "standard world case" from the above source which assumes no relative price increase and no change in recycling rates from the base period.

Figure 5: World Energy Consumption: 1975, 2000, 2025, and 2050



Source: Ridker and Watson, *op. cit.*

Note: See Table 4 for definition of quad.

Table 5. Estimated and Projected World Energy Consumption and Population, Developed and Developing Regions: 1972, 2000, and 2025

Regions	1972				2000			
	Energy consumption		Population		Energy consumption		Population	
	Quads[a]	(%)	Millions	(%)	Quads	(%)	Millions	(%)
Developed[b]	188	(84)	1,099	(29)	384	(67)	1,274	(20)
Developing[c]	36	(16)	2,700	(71)	190	(33)	5,172	(80)
Total world	224	(100)	3,799	(100)	574	(100)	6,446	(100)
United States	72	(32)	209	(5)	114	(20)	264	(4)

Source: Ridker and Watson, *op. cit.*, Tables 2-4 and 5-6.

[a]Defined in note to Table 4.
[b]Developed regions include the U.S., Canada, Europe, Oceania, Japan, and the U.S.S.R.
[c]Developing regions include Latin America, Africa, Asia minus Japan.

cent of total energy, but this share is projected to fall to 14 percent when the country's population makes up just 3 percent of the world total, as also seen in Table 5.

In sum, with the projected slowdown in both rates of population growth and rates of consumption of resources, the answer to our second question appears to be that the lilies (population) and their demands on the nutrients in the pond (resources) are unlikely to grow as rapidly in the future. It is true that the *absolute amount* of resources required will increase dramatically. As seen at the bottom of Table 4, world energy requirements could be five times greater in 2025 than they were in 1975 (1,201 quads versus 237 quads). But this increase is still significantly less than what was anticipated just a few years ago.

This leaves us with our third question: What can be said about the size of the lily pond—the resources—and the extent and speed with which it can expand?

Resource Supplies to 2025

The question of resource supplies in the future is vastly more difficult to answer because it requires projections of new discoveries and techniques of production as well as judgments about rates of diffusion and increases in production capacity. Adequate answers are impossible without highly detailed, quantitative studies, few of which have been undertaken. The best we can do here is to discuss two related questions. In this section we deal with the first: Are resources adequate to meet the demands that are likely to be forthcoming during the next quarter to half century? If so, at least we know we have some breathing space. In the next section, we address the second question: Are resources adequate to meet the level of demand that the world might ultimately have to face on a sustained basis? The answer to that question provides some basis

2025			
Energy consumption		Population	
Quads	(%)	Millions	(%)
637	(53)	1,375	(15)
564	(47)	7,990	(85)
1,201	(100)	9,365	(100)
171	(14)	304	(3)

Note: Based on the "standard world case" from the above source.

with which to consider what types of solutions are required.

Current and prospective reserves

The notion that resources may be inadequate to meet demands in the near future frequently comes from the observation that known reserves of many resources will be exhausted in only a few decades if current rates of growth in consumption continue. There are three problems with this approach.

The first is that current rates of growth in consumption are unlikely to continue, as we have seen. Still, if we had to rely solely on known reserves, there is little doubt that problems would arise within a relevant time frame. The first column of Table 6 (page 26) indicates this fact by showing the dates when prices would have to rise relative to other prices if currently known reserves had to be relied upon. These projections are based on the rates of growth shown in Table 4 and assume that the prices do not increase until the date indicated and that there are no technological changes in production or changes in recycling rates. On these assumptions, it can be seen that currently known reserves of copper, for example, would be exhausted in 2010, reserves of nickel in 2014, and those of petroleum in 1995.

The second problem with this approach is that "exhaustion" dates like those in column 1 of Table 6 do not take into account the fact that current reserves are only a small portion of the resource base. While they are drawn down by consumption, current reserves are augmented through new discoveries, plus technological improvements and increases in market prices which make it economical to mine less concentrated ores. At a minimum, then, estimates of what is likely to be added to these reserves in a given time period because of new discoveries ought to be included. The second column of Table 6 indicates what happens to the dates when relative prices must rise to avoid exhaustion of the nonfuel minerals and energy resources shown if such "prospective reserves" are taken into account.[26]

Figure 6 (page 26) may help clarify the concepts of reserves, prospective reserves, and resources. **Resources** (the entire box in Figure 6) include all the materials that may someday be used. There are no good quantitative estimates of this concept since they depend on all the discoveries, technological changes, and price changes that may ever occur—factors that cannot be predicted. Estimates have been made of minerals in the earth's crust (the outer perimeter to a depth of one kilometer or one mile) but these numbers are clearly too large because it is inconceivable that every last pound of minerals in the earth's crust will someday be mined.

At the other extreme are **current reserves** (upper lefthand box in Figure 6) for which reasonably good estimates generally exist. These are quantities of

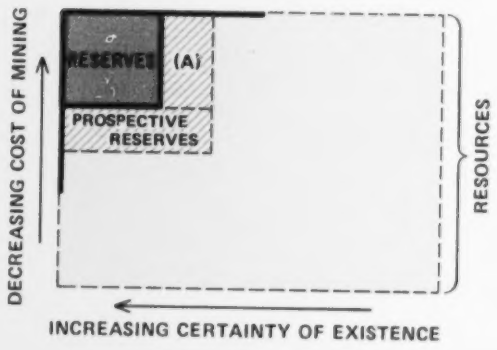
Table 6. Dates When Price Must Rise to Avoid Exhaustion of Selected Resources

	Based on currently known reserves only (year)	Based on reserves plus prospective reserves (year)
Nonfuel minerals		
Aluminum	2025	2038
Chromium	2048	2095
Cobalt	2004	2016
Copper	2010	2041
Iron	2053	2094
Lead	2000	2016
Manganese	2061	2112
Molybdenum	2014	2480
Nickel	2014	2032
Phosphate rock	2034	2120
Potash	2104	2368
Sulfur	2010	2036
Tin	2003	2030
Titanium	2043	2151
Tungsten	2009	2037
Vanadium	2060	2180
Zinc	1993	2065
Energy		
Coal	2050	3000
Petroleum	1995	2010
Natural gas	2005	2024
Uranium	2005	2030-2070

Source: Ridker and Watson, *op. cit.*

Note: These projections are based on the "standard world case" from the above source and assume that recycling rates remain unchanged and that the rate of growth in demand during the 2015-2025 period remains constant thereafter.

Figure 6: The Resource Base



resources that are known and available for economic exploitation with current technologies and at current prices. They are similar to inventories, and since exploration and development are costly, little effort is made to "prove up" new reserves if what is already known is considered adequate to meet demand for the next 10 to 20 years. Even these estimates are incomplete and conservative. Frequently, private companies withhold or underreport such figures. Also, there are many countries for which only incomplete data exist. For example, there are no published data on reserves or prospective reserves of chromium for Oceania, or for copper and phosphate rock in the People's Republic of China.

When current reserves begin to be depleted, the search for additional reserves is intensified. Changes in prices and technology can also affect estimates of reserves. For example, if prices increase or costs of mining decrease, it becomes economical to mine lower grade ores, and the quantities available for current exploitation must be reassessed. **Prospective reserves** is a concept developed to bridge the gap between reserves and resources. It represents estimates of the quantities likely to be added to reserves because of the discoveries and changes in prices and technologies projected to occur within a specified time period. In our case, we limited the term only to discoveries likely to occur during the next half century (portion A of "prospective reserves" in Figure 6).

The third problem with calculating "exhaustion" dates is that this approach says nothing about what is likely to

happen when these dates are approached. Certainly the resource in question will not suddenly disappear from the market at that point in time. Instead, its price will begin rising in anticipation of coming shortages, thereby stimulating mining of lower grade ores and encouraging conservation, recycling, and the search for substitutes. In all these ways, demand is dampened and supplies are stretched, thereby smoothing the transition to another resource regime. Obviously, if the price rise is abrupt and steep, serious disruptions could occur. But consideration of the specifics of individual cases suggests that except for petroleum such an event is unlikely—at least unlikely solely as a consequence of depletion of a given grade of resources.

Aluminum

Consider the case of aluminum, which at 8.3 percent is the third most abundant element in the earth's crust (after oxygen at 45.2 percent and silicon at 27.2 percent). While Table 6 indicates that reserves and prospective reserves would be exhausted by 2038 without a price rise, these estimates of reserves are based only on aluminum from bauxite. Given today's technology, the price of bauxite would have to rise by at least 20 percent and perhaps as much as 80 percent (the latter equivalent to a 10 percent increase in the price of finished aluminum) to justify switching to much more abundant nonbauxite sources of aluminum such as clay and shale. But because of technological developments which will improve the efficiency of obtaining aluminum from these sources, this cross-over price is likely to fall significantly over time—certainly before bauxite is exhausted. Thus it is possible, with adequate planning, that nonbauxite sources of aluminum will be phased in as bauxite is depleted so that no serious economic consequences ensue.

Nickel, copper, cobalt

Other examples are nickel, copper, and cobalt, all of which are listed in Table 6 as having hypothetical exhaustion dates prior to 2045. But the reserve and prospective reserve figures listed in that table include only land-based resources. Once seabed sources of these three minerals are added in—which surely will be appropriate to do during the next 25 years or so—the world reserve figures of these minerals could increase enormously. It has been estimated, for example, that prime areas of the ocean floor contain 29 billion dry tons of nodules which in turn contain 435 million tons of nickel, 348 million tons of copper, and 72.5 million tons of cobalt, plus 7.25 billion tons of manganese.[27] And new nodules are estimated to be forming at the rate of 10 million tons per year, although only a fraction of this increase occurs at likely mining sites. Indeed, the future problem with nickel, copper, and cobalt may not be shortages but falling relative prices for land-based supplies of these minerals which could hurt prospects for the developing countries that are major producers, for example Zaire, which produces cobalt, and Peru and Chile, important producers of copper.

Oil

The situation with respect to petroleum is not too dissimilar. In this case, the analysis underlying Table 6 suggests that *in the absence of political constraints* production could keep up with the growth in demand without a real price rise above its current level until sometime between 1995 and 2010 (depending on a variety of assumptions about income and price elasticities, the cost of substitutes, how rapidly they can be brought into use, etcetera). This is not to say that cartel actions or production shortfalls like those occurring in Iran will not increase the price before that date; but thereafter the price *must* rise

in order to hold demand in line with production from a diminishing resource base.[28] However, the increase in the price of petroleum will make it profitable to produce synthetic liquid fuels from other far more abundant sources such as oil shale, tar sands, coal, and possibly also vegetation (which can be used to produce alcohol). Given today's technology, it would take a 50 to 90 percent increase in the price of oil to justify the switch to liquid fuels from such sources, but by the turn of the century the necessary increase in price may be more like 10 to 20 percent. Here again, it is not long-term exhaustion we must worry about but the shorter term problems of import dependency and the longer term problems of making the transition from one energy regime to another in an orderly way. Such problems could prove especially difficult for poor countries which are deficient in alternative fuels such as coal. (Of the currently estimated total world resources of coal, 35 percent are found in the U.S.S.R.; 35 percent in the People's Republic of China; and 19 percent in the U.S.) It will take substantial foresight, planning, and good will to forestall these difficulties.

Economic impact of rising prices

But suppose our assessment is incorrect, that in fact resource prices in real terms have to rise quite substantially over the next 50 years to balance demands and supplies. How much impact might this have on the world economy?

Countries with supplies of these resources to export—many of which are developing countries—will benefit, of course, and importing countries will be hurt. But the impacts are likely to be modest, except in small, highly specialized economies such as Zaire (which depends on cobalt), Zimbabwe-Rhodesia (dependent on chromium), and Gabon (manganese). The cost of mineral ores is only a part of the total cost of the metals that are produced from them—11 percent for bauxite, 30 percent for iron, and 60 percent for copper, for example. And these metals in turn are only a small fraction of the cost of finished goods. The same is true with energy (except in the energy sector itself). In the U.S., for example, nonfuel minerals account for less than one-half of one percent of the total output of goods and services, and energy costs comprise less than one percent. In the agricultural sector of the U.S., energy is projected to account for 3.1 percent of production costs in 1985 and would not rise to more than 5.6 percent even if energy prices were to double between 1975 and 1985. The fact that energy costs are still a small fraction of total output in major consuming countries, plus the fact that the petrodollars accumulated by OPEC were recycled relatively quickly, explains why even the fourfold increase in oil prices in 1973 did not reduce economic growth rates by more than 2 or 3 percent in most countries, according to one estimate.[29]

Resource-deficit poor countries, for whom the foreign exchange costs of nonfuel minerals and energy constitute a larger fraction of total output, would be hurt the most by substantial price increases. If large enough, such increases could force these countries to scale back development programs. And energy price increases could force the poor within these countries to rely more heavily on wood, thereby exacerbating tendencies toward deforestation and attendant erosion and flooding problems. The majority of these countries did not fare badly after the 1973 petroleum price increase, largely because of the sizable loans made available to them at the time. But as their debt service burdens continue to mount, it remains to be seen whether loans to cover further cost increases will be as easy to obtain.

Some have argued that this assessment of the impact of resource price

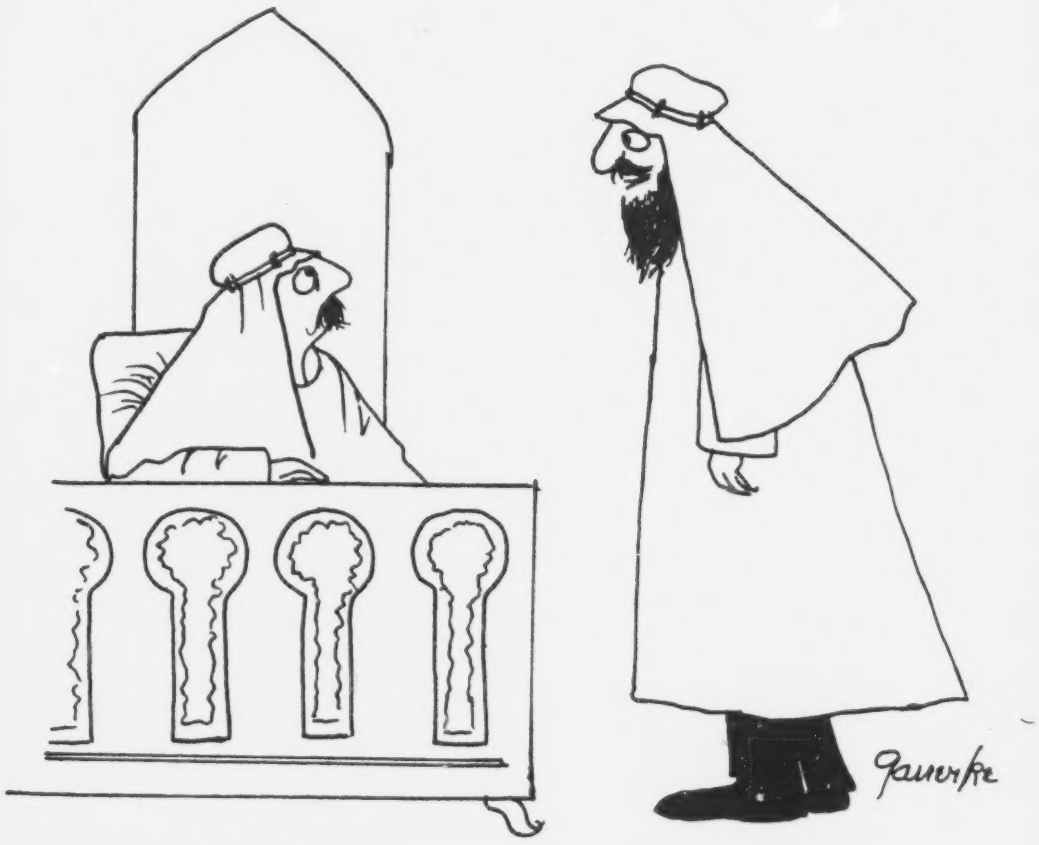
increases does not take into account the greater amounts of energy that will be required as high-grade ores are exhausted and lower grade ores come into use. But the extraction of useful metal from mineral ore involves both mining and "beneficiation" of the ore, and reduction and refining of the metal from the beneficiated ore. Generally the first step requires far less energy than the second. Goeller and Weinberg point out, for example, that "to mine and beneficiate 1 ton of iron from presently used magnetic taconite ores requires about 5 percent as much energy as is required for the total production of steel from ore. Thus, the overall energy required is not very sensitive to the grade of ore until the ore becomes extremely dilute."[30] They go on to explain that the use of such diluted mineral ores will not be necessary. In the long run, most of our metal needs can be supplied by iron, aluminum, and magnesium, all of which are extractable from essentially inexhaustible sources. (As noted, aluminum is the third most abundant element in the earth's crust. Iron, 5.8 percent of the earth's crust, is the fourth, and magnesium, 2.8 percent, is the sixth.) Still more importantly, Goeller and Weinberg find that the energy required to produce these metals from such inexhaustible sources is in each case not more than about 60 percent higher than the energy required to win the metals from more concentrated high-grade ores.

The attempt to supply necessary resources during the next quarter to half century could lead to capital shortages during some periods, however. On the one hand, investment requirements to develop new sources of minerals and energy and (at least in industrial countries) to meet new environmental and health standards are likely to rise substantially. In the U.S., for example, requirements for developing new sources of energy are alone expected to increase from 6.3 percent of total capital needs in 1972 to 9.5 percent in the mid-1980s before dropping back to more normal levels.[31] On the other hand, uncertainties over the course of future prices of minerals and energy, the terms on which exploitation can occur in many countries, and local opposition to the siting of nuclear power plants and mines appear to be growing. The result could be a reduction in venture capital at just the time when investment requirements are at their highest, with inflation and shortages during some periods, even though in a physical sense the resources are there to be exploited.

Overall picture to 2025

There is, of course, a good deal of uncertainty in the picture we have sketched of resource supplies during the next half century. Estimates of reserves and of rates of additions to reserves are poor. Technological developmen.. such as nuclear fusion that could guarantee energy supplies for centuries may come along sooner or later than we think. After the near-meltdown of a nuclear reactor at Three Mile Island near Harrisburg, Pennsylvania, in the spring of 1979, and especially if such accidents are repeated, the U.S., and perhaps other countries as well, may decide not to live with the risks of nuclear fission. Cartels controlling sources of supplies can be established or break up. Environmental problems, which we discuss at the end of this *Bulletin*, could be severe.

Our point in this section is a limited one: that depletion of minerals and fuels and rising world resource prices are not the central problems we face in the next half century. Rather, we face transitional problems—problems of adjusting to increased oil prices, problems of bringing new energy and mineral sources on stream in an orderly fashion, and problems associated with changes in the global distribution of suppliers as new reserves of resources need to be tapped and the balance of power shifts as a result.



"Before they get the idea to hike their wheat prices to the degree we've hiked our oil prices, I propose we buy the State of Iowa."

Gaurke in the *National Review*, 150 East 35th St., New York, NY 10016

While these problems are in part a legacy of the population and economic growth that has occurred so far, they will not be greatly affected by likely changes in these growth rates during the next half century. The Ridker-Watson study found that cumulative energy requirements from 1975 to 2025 would be reduced by 8 percent if the world's population were to grow to 6.7 billion rather than 9.4 billion in 2025, a decline of 29 percent, and by 16 percent if world GNP per capita were $2,600 instead of $3,900 (both in 1971 dollars) in 2025, a decline of 33 percent. Much of the reason for this difference in response is the fact that a slowdown in *population* growth rates would mean an increase in the rate of per capita economic growth, which would partially offset the decline in energy requirements due solely to changes in population, while a slowdown in *economic* growth has far smaller feedback effects on population growth. Indeed, if there is any effect it is likely to be in poor countries where population growth might be reduced by the fall in the standard of living because of a rise in the death rate. But the impacts on energy requirements of each of these changes taken independently are relatively small. It would

take the combined impact of slowdowns in both population and economic growth rates to make a more significant difference. If, for example, both the reductions discussed above were to occur simultaneously, a 25 percent savings could be achieved over the 50 years to 2025. But even then, because of the enormous magnitudes involved, that 25 percent savings could be used up in four or five more years of population and economic growth. (Needless to say, a slowdown only in U.S. population and economic growth rates would accomplish even less; indeed, within the limits that the Ridker-Watson study experimented with, it would save little more than a year's worth of global energy consumption in 2025.) Thus a slowdown in population growth, particularly if it came along with a slowdown in economic growth, would buy a little time with which to find solutions—and that could be very important—but by itself it does not constitute a solution.

Ultimate Resource Production Possibilities

But what lies beyond the next quarter to half century? Suppose, for example, that world population reached an equilibrium of 10 to 12 billion, roughly in the range projected by the United Nations, as noted above. Could such a population be sustained more or less indefinitely at a reasonable standard of living, utilizing currently known technologies?

Food production

So far as agriculture is concerned, two points can be made which suggest that this question can be answered in the affirmative.

First, agricultural production takes place in the world in a wide variety of ways. The Japanese, for example, have achieved high productivity levels by using relatively little land but a great deal of labor and chemical inputs. In contrast, the U.S. uses little labor but a great deal of land and mechanized inputs to achieve similar productivity levels.[32] Both approaches, however, are based on a highly developed scientific infrastructure and substantial inputs of energy. Given these two ingredients, there appears to be sufficient flexibility in agricultural production techniques to achieve reasonable levels of productivity in most countries.

The second point has been made by Roger Revelle.[33] He asked how many people could be fed if yields comparable to those obtained by Iowa corn farmers—which are not the highest in the world—were achieved globally on all arable land. Without utilizing arable land in the humid tropics, which has special problems, his answer is that 7.6 billion people could be supported on a minimum subsistence diet of 2,500 kilocalories per day. But if the problems of utilizing land in the humid tropics can be solved, a diet of between 4,000 and 5,000 kilocalories per day (including high-quality protein and "protective foods" such as fruits and vegetables) could be achieved for from 38 to 48 billion people. (The average American today consumes 3,400 kilocalories per day.) Such levels of output may never be feasible because of organizational and institutional limitations. But this exercise is useful to make it clear that sheer availability of land and water is not the central problem in feeding the world's growing numbers. Rather, it is the disparities in the distribution of people on the one side and production capacity on the other, plus the barriers that stand in the way of eliminating these disparities. By production capacity we mean the whole package of inputs necessary to produce adequate quantities of food—scientific know-how,

trained manpower, and adequate institutions, as well as land, energy, water, and other physical inputs.

Nonfuel minerals

The situation with respect to nonfuel minerals is similar. There is no danger that the world will "run out" of minerals as a whole. The question is whether more abundant minerals can be substituted for the less abundant without substantial increases in cost. With three exceptions, Goeller and Weinberg argue that they can; that societies can subsist on nearly inexhaustible minerals with little loss of welfare.[34] Detailed studies of cadmium, zinc, lead, copper, tin, and mercury indicate that materials such as iron, aluminum, silicon, magnesium, and titanium can be substituted in practically every use; and other studies find that these abundant materials can be acquired from lower grade ores which are in nearly inexhaustible supply, provided that sufficient energy is available at reasonable cost, both economic and environmental. In addition, glass and cement from virtually unlimited sources (sand, clay, gravel) and plastics and some minerals derived from renewable wood and plant sources can be substituted for many of the minerals that might eventually be exhausted.

The exceptions—important resources which are not in inexhaustible supply—are fossil fuels (oil, natural gas, and coal), phosphorus, and a few elements which are essential in trace amounts for agricultural production, such as copper, zinc, and cobalt. While reserves and prospective reserves of coal, phosphorus, and these trace elements are adequate for hundreds of years, they cannot be considered inexhaustible. Ultimately, phosphorus and the trace elements may have to be reserved for agricultural use and returned to the soil by recycling agricultural and animal wastes, and perhaps even bones. But fossil fuels cannot be recycled; eventually, a replacement must be found even for coal.

In addition to substitution, recycling can stretch supplies of nonfuel minerals. This also has the advantage that the energy required to put materials back into productive use is generally less than that needed to reduce and refine ores. Goeller and Weinberg point out, for example, that for magnesium the remelt energy is 1.5 percent of the energy required to win the metal from virgin ore; for aluminum it is 3 to 4 percent; and for titanium it is 30 percent.[35]

Energy

Thus, the key to the long-run sustainability of life on earth is energy. If there is sufficient low-cost energy and if it can be utilized without adverse environmental effects, land can be reclaimed, seawater can be desalted, fertilizers produced, lower grade ores mined,

World Bank photo by Ray Witlin

Harvesting oil palm fruit in Papua New Guinea. Solving the problems of utilizing land in the humid tropics would help feed growing global numbers, providing disparities in the distribution of people and agricultural productive capacity can be overcome.

metals recycled, and substitutions made between minerals so that a reasonable standard of living can be sustained on a long-term basis. If not, an eventual deterioration in the standard of living is inevitable.

According to Goeller and Weinberg, a reasonable standard of living for 10 billion people would require 60 terrawatts of energy a year.[36] This figure compares to about 7.5 terrawatts used today and is about 1/2000 of the energy absorbed from the sun. Can a 60 terrawatt world be reached and sustained?

Nonrenewable sources of energy. Although world resources of *petroleum* and *natural gas* are likely to be essentially exhausted in the next 50 to 75 years, *shale* and *tar sands*, which are widely dispersed about the globe in what are estimated to be very large quantities, could extend the role of oil considerably longer, providing their environmental problems can be solved. *Coal*, used directly or converted to synthetic liquid fuels and gases, could alone supply the energy needs of 10 billion people for several hundred years.

Nuclear fission is a method of producing steam to generate electricity from uranium, a nonrenewable resource. Current estimates of ultimately recoverable uranium vary widely, partly because there has been little incentive to explore for lower grade ores. If the lowest of these estimates is correct, 15 percent of this resource will remain in 2025; if the highest, 77 percent. *Breeder reactors* could improve this situation. These can make use of all the nuclear energy of the common uranium-238, unlike today's light water reactors which depend on uranium-235 which constitutes less than one percent of natural uranium, and this would in effect multiply nuclear energy resources by a factor of 100. However, breeders would substantially reduce global security because they produce vastly more plutonium—a necessary ingredient in atomic weapons—than do the light water reactors now in use.

Renewable and virtually inexhuastible sources. *Nuclear fusion* has generally been regarded as a prime hope for an inexhaustible source of energy in the future, but it is still unknown whether useful energy at an affordable cost can ever be obtained through this procedure. The task is mindboggling: a mixture of heavy hydrogen gases must be brought up to 100 million degrees Celsius, many times the temperature of the sun, and kept there long enough for energy-releasing reactions between hydrogen nuclei to yield a net output of energy. The principal advantage of fusion is that its raw materials (for example, deuterium and lithium) are available in virtually unlimited supply in ocean waters. But it is not true, as once believed, that fusion is completely free of the radiation and waste disposal problems associated with fission.

Even if fusion at reasonable cost never becomes a reality, a global population of 10 billion could probably be supported by *solar energy* in its various forms. The solar energy incident on earth each day is more than 1,000 times the amount of commercial energy now consumed daily. But sunlight varies from place to place, during different periods of the day and year, and with weather conditions. This complicates the process of collecting, storing, and converting solar energy into usuable energy. However, fixed-location solar collection systems are already operating on a small scale in many countries and could eventually supply as much as 60 percent of residential and commercial requirements for space conditioning and water-heating. Eventually, also, it might be economic to convert solar energy into electrical energy using conventional collectors, ground-based systems based on arrays of photovoltaic cells, or possibly even systems based on photovoltaic arrays mounted on satellites orbiting through space.

Solar energy can also be utilized through its conversion into combustible fuels by photosynthesis in trees, plants,

and algae. It is possible that significant amounts of man's energy needs could in time be met by synthetic fuels such as ethanol or methane produced from organic matter (biomass) grown in "energy plantations" on land or at sea, or from organic wastes from agricultural and forestry operations and urban trash. Brazil, with its program to fuel vehicles with ethanol produced from sugar cane, is already moving in this direction.

Wind, tides, thermal gradients between the ocean's warmed surface and cooled depths, and hydroelectricity provide other indirect means of tapping solar energy. Of the four, hydroelectricity is by far the most widely used today in countries well endowed with falling water such as Canada, Norway, the U.S.S.R., and Japan. Estimates put hydroelectricity's worldwide potential at about 110 quads of energy per year, but it is unlikely ever to provide more than 7 percent of the world's energy requirements, the same proportion which it provides today. High costs, land use problems, competing claims for the water, and environmental problems are likely to inhibit its rapid development.

Geothermal heat stored in water pockets or dry "hot rocks" below the earth's surface is a final potentially large source of more or less inexhaustible energy. Hot rocks alone, though now not economically exploitable, are estimated to contain as much energy as all currently estimated nonrenewable energy sources worldwide other than coal.[37]

The economic cost of tapping any or all of these potential sources of inexhaustible energy is virtually impossible to calculate. If reliance had to be placed on a combination of nuclear fission and solar energy today, the cost of energy might have to triple. Some day these costs will come down (in real terms) as researchers dig into these problems. But what they might be after a century of research is anybody's guess.

The environmental and other side effects of using 60 terrawatts of energy each year are likely to be more serious, and some may eventually prove to be intractable. These consequences, then, may be the ultimate key to whether a global population of 10 billion is sustainable at a reasonable standard of living.

Environmental Constraints and Risks

We have reserved most of our discussion of environmental and related problems to this section because they do not fit easily into specific time periods and because some of them, we suspect, might in the end prove to be the most severe and difficult to resolve of all the problems the world faces in coming decades.

It is convenient to group these problems into three categories. The first includes those problems that can be controlled at reasonable cost with current technology, in particular the mass pollutants of air and water like particulates, sulfates, hydrocarbons, carbon monoxide, and suspended and dissolved solids. The second category covers other environmental problems whose impacts are mainly local or national in scope. Examples here are conflicts over land use, including siting of power plants and mining operations, water shortages, nuclear reactor accidents, disposal of spent nuclear fuel, local weather modifications, and soil erosion. The third group involves problems that are more global in scope, for example, global climate changes, nuclear proliferation, and ocean pollution.

Problems capable of control at reasonable cost

If pollution emissions per unit of output were to remain constant in the future, environmental concentrations of the

mass pollutants would soon rise to intolerable levels in many regions of the world, affecting not only amenities but also the productivity of labor, land, and fisheries. But most of these emissions can be controlled at modest cost. In the U.S., for example, we have estimated that, without controls, the cost of pollution damages would have been the equivalent of 8.6 percent of the Gross National Product (GNP) in 1975. But actual damage costs in 1975 were closer to 3.2 percent of GNP because of control policies costing about 1 percent. With the enforcement of environmental laws already passed, such as the National Environmental Policy Act of 1969 and the Clean Air Act of 1970 and its subsequent amendments, plus anticipated changes in the next two decades, pollution damage and control costs in the U.S. are projected to amount to 1.5 percent and 2 percent of GNP respectively by the year 2000. These figures allow for some slippage from strictly enforced standards when resource pressures mount. A case in point is the Environmental Protection Agency's suspension in May 1979 of its ban on a gasoline additive which increases hydrocarbon emissions in order to allow more unleaded gasoline to be produced during the gasoline shortage. If there were no such slippages, pollution damage and control costs in the U.S. might be more like 1 percent and 3 percent of GNP, respectively, in 2000.[38]

Thus, for this category of environmental problems, pollution control policies are more important in determining what happens than are population and economic growth rates. In countries where these policies are weak, pollution problems can be expected to mount at least as fast as the growth of GNP, that is, much faster than the growth of population alone. But in countries where stringent policies are applied, these problems can be reduced to acceptable levels at costs that are relatively modest compared to the value of total output.

Photo by Harold M. Lambert

Solar collection systems could eventually supply as much as 60 percent of residential and commercial requirements for space-conditioning and water-heating.

Other domestic environmental problems

Problems in this category differ from those in the first group in three ways.

First, either the technologies or the institutions for controlling these problems are not as well worked out. In most countries there is considerable room for improving efficiency of water use, but the institutional mechanisms for allocating water among users are seldom well developed. Methods of controlling soil erosion are well known but difficult to apply because widely dispersed farmers have incentives to maximize short-run production and, if necessary, to compensate for erosion losses by using more fertilizer, adding marginal lands, and reducing fallow periods. Land reclamation procedures for arid regions pose special problems that are not yet solved. The probability of nuclear accidents cannot be reduced to zero any more than can that of accidents in coal mines; yet the more accidents there are,

the more difficult the siting problems will become.

Second, many of these problems will show up in conflicts among local groups or between regional and national interests: for water rights, for power plant and mining sites, for conversion of agricultural lands, and so on. While difficult to predict, these conflicts could at times become so severe and widespread that national economic growth is affected.

Third, until solutions are found to these problems, they are likely to mount with population and economic growth, unlike what we expect in the case of most mass pollutants. For example, Ridker and Watson found that if the U.S. population in 2025 were 28 percent less than the 304 million projected in one of their scenarios, there would be 12.5 percent less land disturbed by mining, 25 percent fewer electric power plants, and 23 percent fewer nuclear power plants, and thus many fewer occasions to arouse local opposition to environmental threats.

Potentially severe global problems

Frequently mentioned examples of global concerns regarding the environment are changes in global climate, ozone depletion, ocean pollution, and nuclear proliferation. In addition, there are a variety of potentially serious regional problems that could have global repercussions. Among these are the loss and deterioration of soils, loss of genetic variability due to the spread of monoculture, release of long-lived radiation from uranium mill tailings, nuclear reactor accidents and problems of waste storage, and the proliferation and buildup of toxic chemicals in food chains.

For a variety of reasons, virtually all the problems in this category are unlikely to be effectively controlled in the near future. In some cases, control is technically and institutionally difficult. Ultimately, for example, the spread of nuclear weapons depends only on the diffusion of relevant knowledge and this is almost impossible to control. Controlling the worldwide increase in nuclear power plants—which itself may be impossible—may thus only marginally delay the spread of nuclear weapons. It may be possible to control the buildup of carbon dioxide in the atmosphere from increased burning of fossil fuels but only by herculean means involving global agreements to capture it from stack gases, reverse the trend toward deforestation which removes the trees to absorb it, and, in the end, perhaps reduce combustion itself.

But these difficulties are frequently compounded by insufficient knowledge to judge whether controls are needed at all and, if so, how strict they should be. Do carbon dioxide and the spread of fission reactors have to be controlled, or can we wait, hoping that less environmentally damaging alternatives such as solar and possibly nuclear fusion energy will come along before these problems become acute? What level of risks are we really subjecting ourselves to when we allow more nuclear plants to be built; and how do they compare with those we accept in other areas like coal mining and with those we could face in the absence of nuclear power, such as a drop in living standards? Then, too, it is difficult to mobilize support for such actions. Even with the same facts, countries with little coal and no oil are likely to view the risks and benefits of nuclear energy quite differently from the U.S.

As a consequence, these environmental pressures can also be expected to increase with population and economic growth. Whether they will become so severe during the next half century as to limit such growth is an open question. They could if the more pessimistic assumptions about carbon dioxide and the risks of nuclear power prove to be true, or if a number of

these types of pressures act in concert to overload ecological systems. But little confidence can be placed in these —or any other—assumptions.

The carbon dioxide problem provides a good illustration of the extent of our ignorance. Historically, approximately half the carbon dioxide released by combustion of fossil fuels has remained in the atmosphere. If this fraction continues to apply in the future and population and economic growth continue, atmospheric concentrations of carbon dioxide would rise to about twice pre-industrial levels by 2050. According to one relatively sophisticated climate model, that increase would, through the "greenhouse effect," raise the average global temperature by 1.5 to 3.0 degrees Celsius. Such a rise, unprecedented in recorded history, would force dramatic shifts in the global distribution of plants, animals, and man himself; shift storm belts to different areas; reduce the productivity of ecosystems; and eventually begin to melt polar ice and thus raise sea levels. But the estimate of a 1.5 to 3.0 degree increase is based on a model that ignores a number of factors. Higher temperatures would increase evaporation and thus cloudiness would block out incoming heat, and other air pollutants such as particulates could also reduce global temperatures. On the other hand, still more carbon dioxide may accumulate as higher temperatures reduce the capacity of oceans to absorb it; and recent studies by ecologists suggest that deforestation has been so widespread that land plants on net have been releasing rather than absorbing carbon dioxide.[39] Taking these factors into account provides a range of possible dates when a 1.5 to 3.0 degree increase in temperature might occur which extends from as early as 1990 to perhaps never.[40] This is hardly a useful basis for policy decisions.

Similar uncertainties surround the impact of nuclear power generation. While it is known that large doses of radiation can kill a person almost outright and small doses lead to cancer immediately or many years later, the long-term effects of small doses of radiation on large human populations are not known. The relationship between genetic disorders and low-level radiation is also obscure. It is known that radiation increases the rate of mutation but the eventual effects of a mutation depend on additional complex genetic and environmental factors which vary widely for different mutations. Moreover, our experience to date with nuclear power is so limited that it is impossible to evaluate with confidence the probabilities and seriousness of accidents or to determine how to safely store spent nuclear fuel for the thousands of years that it must be isolated from the human environment. No spent fuel has been permanently disposed of yet by any country.

These are all areas of extreme uncertainty and high costs of error. The growth of such uncertainties and risks might be slowed somewhat by restricting population and economic growth. But they cannot really be reduced except by getting on with the task of developing alternatives to fossil fuel combustion and nuclear fission, finding ways to store and safeguard nuclear wastes, and improving our knowledge of carbon dioxide transport mechanisms and the biological effects of radiation.

Implications

Consideration of this array of both shorter and longer term problems should lead one to question the usefulness of both the Limits and the Cornucopian views of the future of man. During the next quarter to half century, the world will be faced with a series of transition problems requiring the substitution of one resource regime for another—in particular from reliance on petroleum

Photo by Harold M. Lambert

A potentially severe global problem is the buildup of carbon dioxide in the atmosphere from increased fossil fuel combustion.

and natural gas to other fuels. In the process, some countries and groups within countries will be hurt while others are benefited. This could cause tensions which, like shifts in the earth's plates that cause earthquakes, eventually burst to the surface. All the while, uncertainties and risks of the type just discussed will undoubtedly mount. As a consequence, the earth could become an increasingly dangerous place to live.

Population and economic growth play important roles in exacerbating these problems in those cases where other means of resolving them are not present or are not adequately implemented. For example, in countries with strictly enforced pollution control policies, economic and population growth need not generate significantly greater quantities of pollutants; and in countries with the capacity to develop synthetic liquids and gases from other available resources, the depletion of petroleum and natural gas reserves should not be a cause for great alarm. More generally, the greater a country's scientific and institutional capacity to resolve problems, the higher the sustainable rate of growth can be without overloading the system. As a consequence, the linkage between population and economic growth on the one hand and resource and environmental problems on the other tends to be looser in developed countries and tighter and more unforgiving in developing countries. But rapid rates of population and economic growth cause at least some problems everywhere. What can be done about them?

Should population growth be restricted? Certainly, for this would slow the speed with which all the problems we have discussed must be solved and reduce the ultimate size of the global population which will have to be sustained, once zero population growth is reached. An equilibrium population of 10 billion in place of the 11.5 billion now projected by the United Nations would present that many fewer problems for the long term. A smaller one would be still better. But even a cessation of population growth cannot resolve all these problems or keep them from mounting over time.

Should per capita economic growth be restricted? Unlike a cessation in population growth, the consequences of an economic slowdown are ambiguous. On the one hand, it would help in the same sense as a slowdown in population growth, by providing more time to find solutions. On the other, it would mean less trained manpower and less surplus output that could be diverted to search for and implement solutions.

Each new birth brings with it an additional packet of resource and environmental problems. In contrast, economic growth can be utilized for different ends than it is put to now. While it adds to the problems that need solution, it also adds to the capacity to solve problems.

Moreover, considering poor countries' legitimate aspirations for a decent standard of living and the unwillingness of the rich to voluntarily redistribute

wealth on any significant scale, a slowdown in economic growth is likely to lead to conflict. If nuclear power continues to spread, the results could be devastating. From this perspective, the risks of restricting economic growth may be substantially greater than the environmental and resource problems associated with its continuation.

Should greater efforts at conservation of resources be made? By all means, again on the grounds that it buys time. Indeed, if taken seriously, it should be a better buy in the next decade or so than a slowdown in population growth, whose consequences will take more time to be felt. Turning the thermostat down in winter and up in summer and installing thicker insulation shows up almost immediately in lower monthly oil consumption and bills. Moreover, it appears that considerable savings in energy consumption can be had without sacrificing either personal comfort or economic growth.[41]

But in the end, all these problems will remain until they are directly confronted and attacked. Uncertainities about the effects of more carbon dioxide in the atmosphere can only be reduced through fundamental research into climatology and related fields. Risks associated with nuclear fission can only be contained through improved security measures and efforts to find and adopt acceptable alternatives. Poverty-stricken countries and impoverished groups within countries can only be helped by lifting the barriers to the flow of resources, knowledge, and technical and managerial skills into, and/or people out of, these regions, and so on.

There is no simple explanation for these problems; equally, there are no simple solutions. We have no choice but to work on both the causes and the symptoms simultaneously. Understanding the true nature of the world's resource and environmental limitations is a first step in that direction. □

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